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FINAL REPORT

REVISED

Hydrogeology of the Oak Ridge Gaseous Diffusion Plant

DECEMBER 1989

Prepared for

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HYDROGEOLOGY OF THE OAK RIDGE GASEOUS DIFFUSION PLANT

Prepared for the

Oak Ridge Gaseous Diffusion Plant
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

December 1989

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1.0 EXECUTIVE SUMMARY

On July 22, 1985, Martin Marietta Energy Systems, Inc., (Energy Systems), contracted with Geraghty & Miller, Inc.(Geraghty & Miller) to (1) evaluate the need for ground-water monitoring at 29 waste-storage/disposal sites, (2) conduct an investigation to characterize the hydrogeology, and (3) design a ground-water monitoring program for these sites at the Oak Ridge Gaseous Diffusion Plant. Work began August 1, 1985. A report, "Requirements for Ground-Water Monitoring at 29 Waste-Storage Disposal Sites at the Oak Ridge Gaseous Diffusion Plant", was delivered in September 1985 (Geraghty & Miller, Inc. 1985b). Thirteen of the 29 sites were determined to require further evaluation. Tennessee Department of Health and Environment (TDHE) suggested that one additional site be included, bringing the total number of sites studied to 14. The 37 ground-water monitor wells and piezometers constructed for the evaluation of these 14 sites were installed in conjunction with Phase I of the ORGDP Ground-Water Protection Program.

After reviewing the hydrogeologic data from the characterization wells, Geraghty & Miller prepared a ground-water monitoring plan encompassing the 14 sites (Geraghty & Miller, Inc. 1986a). During the fall and winter months of 1986/1987, Geraghty & Miller installed 41 ground-water monitor wells at the 14 sites. These wells were installed as part of Phase II of the ORGDP Ground-Water Protection Program.

Sampling of the monitor wells at the K-1407-B and K-1407-C Ponds began in December 1985. These samples were analyzed for volatile organic compounds, base neutral, and acid extractable compounds, metals, gross alpha and beta, pesticides, herbicides, and PCBs. The results and evaluation of these analyses are presented in "Ground-Water Quality at the Oak Ridge Gaseous Diffusion Plant", (Geraghty & Miller, Inc. 1989b).

In March 1987, Energy Systems contracted with Geraghty & Miller to evaluate the need for ground-water monitoring at an additional 39 waste-management sites. Twenty seven of the 39 sites were determined to require further evaluation as described in the report "Requirements for Ground-Water Monitoring at 39 Waste Management Sites at the Oak Ridge Gaseous Diffusion Plant" (Geraghty & Miller , Inc. 1987). During the summer of 1987, Geraghty & Miller installed 45 monitor wells at the 27 sites. Wells installed at these sites were constructed as part of the Phase I Extension of the ORGDP Ground-Water Protection Program. In addition, 4 wells were added to the monitor-well network for the original 14 sites and 5 temporary shallow wells and 2 bedrock wells were added to the K-1414 site (Geraghty & Miller, Inc. 1988a).

In September 1988, Geraghty & Miller submitted a ground-water monitoring plan for the 27 waste-management sites. The purpose of the proposed monitor-well network was to provide additional hydrogeologic and water-quality data; determine the presence, concentration, extent, and rate of migration of contaminants; and to meet state and federal regulations.

In January 1989, Energy Systems contracted Geraghty & Miller to implement the proposed monitor-well program through an extension of Phase II of the prime subcontract. The scope of the program originally consisted of the installation of 26 unconsolidated zone and 23 bedrock monitor wells. One additional unconsolidated zone well was later added to the program. Due to auger refusal at depths too shallow to practically construct a well, two of the unconsolidated zone wells were abandoned and one was deepened in order to construct a well in the bedrock. Work, which consisted of the installation and development of 24 unconsolidated zone and 24 bedrock monitor wells, began in April 1989 and concluded in July of the same year. Documentation regarding the installation of these wells is provided in Geraghty & Miller, Inc. 1989a.

This report is a revision of the hydrogeology reports previously issued by Geraghty & Miller (1986b and 1988b)). A revised report was deemed appropriate because of the additional information acquired from the Phase II Extension drilling and revisions to the geologic map based on this new data and the re-evaluation of the previously obtained data. This report presents a compilation of the methods used and the hydrogeologic data collected during Phase I, Phase I Extension, Phase II, and Phase II Extension of the ORGDP Ground-Water Protection Program, also included is the revised geologic interpretation of the Plant site.

Ground water in the area is derived from local precipitation that infiltrates the uppermost aquifer and, in some areas moves into underlying bedrock aquifers. Ground water flows from areas of recharge, downgradient, along relatively short and shallow flow paths toward areas of discharge. Discharge from both the surficial and bedrock aquifers is to the banks and bottoms of the Clinch River and Poplar Creek.

Rate of ground-water flow in the surficial aquifer, based on slug test results, is very slow, on the order of 10^{-1} ft per day, due to the low permeability of the unconsolidated aquifer material and the low gradients in the area. Movement of ground water through fractures and solution conduits in some of the carbonate bedrock aquifers is quite rapid, even where gradients are not particularly steep. The hydrogeology at each of the 41 waste-management sites is discussed in Section 5.0 of this report. Data collected for the study are included in the appendices.

2.0 INTRODUCTION

The Oak Ridge Gaseous Diffusion Plant (Figure 1) was built in the early 1940's for enrichment of uranium hexafluoride and was in continuous use for that purpose until August 27, 1985. A variety of non-hazardous, hazardous, radioactive, and mixed waste materials have been stored, treated, or disposed at sites within the plant area. Operations at some of the sites have been well documented, but several sites, particularly in the early days of operation, may have received hazardous or radioactive wastes without records having been kept.

In the first stage of each phase of this project, each of the waste-management sites (a total of 68) was evaluated, on the basis of its history and physical situation, to determine whether ground-water monitoring would be required under the various federal and state regulations. The results of these determinations were submitted to Energy Systems. Through these evaluations it was determined that 41 of the 68 sites would require ground-water monitoring to comply with applicable regulations (Figure 2).

2.1 PREVIOUS INVESTIGATIONS

No published reports concerning ground-water contamination investigations prior to Geraghty & Miller's 1986b report, were discovered for the ORGDP area, although a paper by Ketelle and Pin, "Use of Electromagnetic Terrain Conductivity Measurements to Map Liquid Hazardous Waste Migration in Groundwater," delineates a plume of high conductivity that was verified by test drilling in the vicinity of K-1407-C Pond. A report on the ground-water resources of East Tennessee, by DeBuchananne and Richardson, provides a good general discussion of rock types in the area and their hydrogelogic characteristics. Discussions with R.H. Ketelle, who has added considerable detail to geologic maps of the area prepared by Rodgers (1953) and McMaster (1962), among others, were extremely useful to the present understanding of the complex geology of the ORGDP area.

2.2 PURPOSE AND SCOPE

The purpose of this study is to characterize the hydrogeology of 41 Waste-Management sites at the ORGDP. To characterize the hydrogeology at the 41 sites, a total of 180 permanent and 11 temporary test holes were drilled, 113 in the unconsolidated weathering residuum and alluvium that comprise the uppermost aquifer and 78 in the bedrock. As drilling progressed samples of soil and rock were collected, and stainless steel or PVC screen and casing were installed in each borehole. Slug tests were conducted on selected wells to determine the permeability of the aquifers. Measurements of water levels in all of the existing wells were made periodically. Analyses of these data comprise the bulk of this report and lead to the conclusions on the hydrogeology of each of the waste-management sites.

This report also presents the changes to the ORGDP geologic map from the previous versions (Geraghty & Miller, Inc. 1986b, 1988b). The primary revision is the addition of the Conasauga Group in the K-1407 area of the ORGDP. This revised interpretation was fostered as a result of the 1989 drilling program, discussions with R.H. Ketelle of Energy Systems and G. Pruitt of Advanced Sciences, Inc., and re-evaluation of the lithologic logs from previous drilling in the K-1407 area.

3.0 REGIONAL SETTING

3.1 CLIMATE

The climate at ORGDP is influenced by the topographic setting in the Valley and Ridge Physiographic Province. Temperatures are moderated by the higher terrain of the Cumberland Plateau to the northwest and the Blue Ridge Province to the southeast, which divert cold northwesterly winter winds and hot southerly summer winds, respectively. Mean temperatures in the area range from 30 to 49 degrees Fahrenheit in January to 65 to 88 degrees in July.

Precipitation is greatest in late winter and spring, and is associated with large-scale storms. A secondary precipitation maximum occurs in midsummer as the result of summer thunderstorms. Least precipitation, which occurs in late summer and early fall, is associated with slow-moving high pressure cells over the Valley and Ridge. Figure 3 shows mean monthly precipitation from data collected at Oak Ridge from 1959 to 1988.

3.2 DRAINAGE

The ORGDP site lies at the mouth of the Poplar Creek Watershed, in which the general direction of flow is toward the southwest. As shown in Figure 1, a trellis drainage pattern, influenced by the geologic structure, is well developed in this watershed. Poplar Creek meanders through the plant site to its confluence with the Clinch River on the plant's western boundary. The Clinch River flows southwest into the Tennessee River near Kingston, Tennessee. Tributaries of Poplar Creek include Indian Creek, which drains the northwestern portions of the watershed, East Fork Poplar Creek, which is fed by Bear Creek, and Brushy Fork which drains the head of the watershed (see Figure 1).

Energy Systems operates a water intake and treatment plant on the Clinch River at approximately mile 14.5. Clinch River elevations are read from a staff gage at the plant intake. The maximum monthly river elevation for 1985 was 741.83 ft msl, and the minimum monthly river elevation was 734.58 ft msl. Figure 4 shows maximum and minimum monthly elevations for the Clinch River in 1985.

Streamflow and stream stage for the Clinch River and the lower reaches of Poplar Creek are influenced by Watts Bar Dam on the Tennessee River and by Melton Hill Dam on the Clinch River. Backwater from Watts Bar Dam (Watts Bar Lake) extends upstream along the Clinch River to river mile 23 at Melton Hill Dam, along Poplar Creek through the plant site to approximately mile 6, and along East Fork Poplar Creek to approximately mile 1.5. Normal stage for this reach of the Clinch River is 741 ft. Average daily discharge below Melton Hill Dam is 4,538 cfs for the 39 year period of record. The K-1700 Watershed, south of Blair Road, directs runoff from the K-1407 area of the plant through NPDES Station 1700 to Poplar Creek.

The U.S. Geological Survey maintains streamgage stations on Poplar Creek at mile 14 and on Poplar Creek at mile 3.5, both of which are located upstream from the influence of backwaters from Watts Bar Dam. The 24 years of continuous data from these stations indicate that highest flows occur in the spring when precipitation is greatest and lowest flows occur during the late summer and early fall when precipitation is minimal and much of it is evapotranspired by vegetation. Figure 5 shows hydrographs of stage and discharge at Poplar Creek upstream from the backwater effects of Watts Bar Dam along with precipitation at Oak Ridge. The immediate response of runoff to rainfall, apparent in the hydrographs, is due to the relatively steep slopes and clay soils of low permeability.

Surface runoff in the uplands around the plant site is largely controlled by soil cover; whereas, runoff within the plant site is largely controlled by subsurface drains and diversion ditches. The Fullerton Soil Series, the dominant upland soil, has moderate infiltration rates and is moderately drained to well drained. The Nolichucky and Talbott

Series soils are the most abundant valley and terrace soils within the plant site. The Nolichucky soils are similar in hydraulic characteristics to the Fullerton Series. The Talbott soils occur mainly within the inside meander loops of Poplar Creek and are soils having slow infiltration rates and slow rates of water transmission.

3.3 TOPOGRAPHY

The ORGDP site in eastern Roane County lies in the Valley and Ridge Physiographic Province, which is characterized by parallel ridges and valleys trending in a northeasterly direction. Differential weathering and erosion of folded and faulted sedimentary rocks have produced the linear, flat-bottomed valleys and corresponding ridges. Ridges underlain by cherty dolostone, such as Blackoak Ridge and McKinney Ridge, which form the northern and northeastern borders of the site valley, generally have broad well rounded or rolling crests, whereas Pine Ridge, to the south, is underlain by sandstone and shale and is characterized by sharp or pointed crests.

The plant site is located at the confluence of Poplar Creek with Clinch River. Land surface in the study area ranges from about 700 ft above sea level, at the bottom of the Clinch River, to 1,000 to 1,100 ft along the ridge crests. The majority of the plant site lies within the floodplain and terrace lands of Poplar Creek where relief rarely varies more than 25 ft, with slopes averaging 1 percent.

3.4 HYDROGEOLOGY

A variety of rock types underlie the study area. Differences in their lithology, mode of deposition, and manner of weathering all affect the movement of water through them. Although the initial permeability of the limestone, dolostone, and shale that comprise the bedrock was low, geologic events subsequent to their formation have developed zones of secondary permeability by solution, fracturing, and weathering that control the flow of ground water.

3.4.1 Surficial Aquifer

The surficial aquifer is made up of all the unconsolidated material overlying bedrock and consists of man-made fill, alluvium, and the residuum of weathered bedrock. The depth to unweathered bedrock varies from less than 10 to more than 50 ft depending on the weathering characteristics of the underlying rocks. Much of the fill material consists of construction debris, pieces of concrete and wood, and excavated weathered shale, limestone, and chert mixed with clay.

Alluvium is present along the shores of Clinch River and, to a lesser extent, along Poplar Creek. Site K-770 appears to be a floodplain deposit of very fine sand with lenses and layers of silt and clay that extend to depths of about 30 ft, the depth of Clinch River in this reach.

Unconsolidated residuum overlies bedrock throughout the area except in scattered rock outcrop areas and is generally clayey in nature with a varying content of silt, sand, and rock fragments. With increasing depth, the clay gives way to weathered rock that has retained its structural characteristics. Bedding and joint surfaces usually exhibit some type of oxide staining. The transition from weathered rock to fresh bedrock typically occurs through an interval of less than 10 to about 30 ft.

3.4.2 Bedrock Aquifers

The consolidated rock formations in the area are Cambrian to Ordovician sandstones, siltstones, shales, dolostones, and limestones. These strata have been classified into groups and formations based on age, lithology, and fossil content (Keith 1895; 1896a), (Rodgers 1948), (Law 1975). From oldest to youngest, the geologic units are the Shady Dolomite, the Rome Formation, the Conasauga Group, the Knox Group, and the Chickamauga Group.

3.4.2.1 Shady Dolomite

The occurrence of the Shady Dolomite in the vicinity of the ORGDP has been documented through drilling conducted during an unrelated investigation across the Clinch River immediately west of the plant and at the very western edge of the ORGDP property near the K-720 Fly Ash Pile (Geraghty & Miller, Inc. 1981). The occurrence of the Shady Dolomite along strike to the east across the plant area is unknown; however, an occurrence of Shady Dolomite just east of the ORGDP has been indicated by geological field mapping conducted in this area (Ketelle, pers. comm. 1987).

The Shady Dolomite consists of crystalline, gray to light yellowish gray dolostone with lesser amounts of limestone and occasional chert. The Shady Dolomite encountered in drilling across the Clinch River from the ORGDP has been highly fractured and contains numerous vugs. The abundance of fractures and open spaces would provide innumerable avenues for ground-water movement within this formation.

3.4.2.2 Rome Formation

The Rome Formation is a sequence of interbedded sandstones, siltstones, shales, and limestones of variegated olive, maroon, and drab colors. Buff-colored sandstone ledges of the lower Rome Formation form Pine Ridge along the southern border of the plant area (Figure 6). The more shaley upper member of the Rome Formation forms the hill where sites K-1070-C and D are located. The lower member of the Rome Formation is characterized by substantial proportions of impure carbonates ranging from limestone to dolostone (see BRW-9 and BRW-12). Ground-water movement in the Rome Formation is restricted to fractures in the shales and sandstones.

3.4.2.3 Conasauga Group

The Conasauga Group, ranging in age from middle to upper Cambrian, is composed of alternating shale and limestone strata. The shale units are typically green, gray and maroon and are calcareous in places. The limestone units are generally blue-gray, micritic, and are oolitic, cherty, and fossiliferous in places.

Solution activity commonly enlarges joints and bedding planes within the limestone strata of the Conasauga Group, producing cavities. These cavities are an important controlling influence for ground-water flow. Because the shale beds are generally less transmissive, ground-water flow is concentrated in the limestone strata.

3.4.2.4 Knox Group

Dolostone of the Knox Group is dense and commonly siliceous. This relatively resistant rock forms Blackoak Ridge along the northern side of the plant area, as well as McKinney Ridge to the northeast. The upper Cambrian to lower Ordovician strata of the Knox Group consist of gray to blue-gray, thin to thick-bedded dolostone with interbeds of limestone. Soils derived from Knox dolostones are commonly reddish-orange, clayey, and contain abundant chert fragments.

Solution features such as sinkholes and caverns are common in the Knox Group and are an important route for ground-water flow. Rapid movement of ground water through these channels is an important source of many large springs. The Knox Group was exposed to erosion for a period prior to deposition of the overlying Chickamauga Group, and the contact between the two units is a common zone of discharge for springs in many parts of the Valley and Ridge Province.

3.4.2.5 Chickamauga Group

The Chickamauga Group, of Ordovician age, disconformably overlies the Knox dolostone and is the most extensive bedrock unit underlying the plant area. The Chickamauga Group varies in character but is generally a thin-to medium-bedded, argillaceous limestone, with intercalations of silty limestone and shale. Weathering of the shale partings permits ground-water circulation along the bedding planes and consequent dissolution of the limestone. The shale beds restrict ground-water flow across bedding, resulting in concentrated flow along the limestone-shale contact with resultant solution cavities. The cavities form conduits for accelerated flow and are a common source of spring discharge from the Chickamauga Group.

3.4.3 Structural Relationships

The dominant structural feature in the plant area is the Whiteoak Mountain thrust fault which trends northeasterly across the southern border of the plant, roughly parallel to Oak Ridge Turnpike (Figure 6). The Whiteoak Mountain fault is actually a zone of faulting, in which a number of separate fault slices have juxtaposed various geologic units. In the plant area, rocks of the Shady Dolomite and the Rome Formation have been thrust over rocks of the younger Knox Group and Chickamauga Group to their present position along the southern border of the area (Figures 6 and 7). This movement was part of a regional tectonic activity that resulted in the present structure of the Valley and Ridge Province.

A sinuous low-angle fault diverges from the Whiteoak Mountain fault and trends in a northerly direction across the plant area roughly paralleling the topography, truncating two east-trending faults which it apparently postdates. The effect of these faults on the ground-water system has not been determined in any detail, although it is possible that increased weathering of rocks along the fault planes may, in some cases, develop paths of preferential flow (Figures 7 and 8).

Outcrops of Knox dolostones in the valley of Poplar Creek, north of the plant, and of the Rome shales, along Clinch River to the south, show dips at angles ranging from 45 to 60 degrees to the southeast. Limestones of the Chickamauga Group, exposed in the banks of Poplar Creek, exhibit small-scale folding that results in bedding orientation ranging from horizontal to vertical in relatively short distances. The folds generally have axes parallel to the northeasterly regional strike of the bedding.

The presence of joints (fractures) in the bedrock is one of the most important factors controlling the movement of ground water. Joints provide pathways that may become enlarged by dissolution in the carbonate rocks, or, in the case of a shale or well-cemented sandstone, may allow the movement of ground water through otherwise impervious strata. Studies of joints in nearby areas (Law 1975), (Rothschild and others 1984), (Sledz and Huff 1981), indicate that joint orientation and spacing are quite variable. The studies generally agree that there is at least one major joint set that roughly parallels the geologic strike and dips 40 degrees to the northwest. A second steeply-dipping joint set strikes about N12^{o}W.

Joint spacing may vary from fractions of inches to several feet. Generally, the greatest concentrations of joints are observed in siltstones and cemented sandstones, the least in shales and limestones. Joint density is inversely proportional to bed thickness in both shales and siltstones, thus the thinly-bedded Rome, Conasauga and Chickamauga rocks are host to many closely-spaced joints that are a principal path of ground-water movement.

The size of joint openings is greatest in the zone of weathered bedrock and diminishes rapidly with depth. Brittle rocks, such as sandstones, siltstones, and carbonates, are more common hosts to joints than ductile rock such as shale.

3.4.4 Solution Features

Rainfall percolating through humus and soil assimilates humic acids and free carbon dioxide and becomes moderately acidic. The acidic water then reacts with limestone and dolostone bedrock resulting in dissolution of carbonate ions and enlargement of joints, bedding planes, and other zones of accelerated flow. Solution is also accelerated at and just below the water table, where flow is commonly most vigorous and the water has not yet reached chemical equilibrium with the rock. As previously mentioned, both the dolostones and limestones of the Conasauga, Knox, and Chickamauga Groups are subject to dissolution where ground-water flow is concentrated. The importance of solution cavities to ground-water movement lies in the fact that they are numerous, not necessarily cavernous.

3.4.5 Ground-Water Flow

Local recharge from precipitation moves along relatively short flow paths from the areas of infiltration downgradient to the areas of seepage or springflow into the banks and bottom of the nearest reach of Clinch River or Poplar Creek. The relatively moderate relief of the area provides insufficient hydraulic head for deep ground-water circulation, and the bedrock lithology, geologic history, and regional structure appear to provide no deep permeable zones for ground-water flow beyond the local system.

3.4.5.1 Surficial Aquifer

The surficial aquifer can be considered as a single, though complex, unit. At most sites the unconsolidated material is relatively homogeneous and ground-water flow is generally predictable; that is, flow is downgradient, normal to the contours of the water table. Contours of the water table and ground-water flow lines, inferred from water levels in 191 wells, Poplar Creek, and Clinch River are shown in Figure 9. In areas where well data are limited, interpretation is augmented by judgment based on topography and on known or inferred hydrologic characteristics.

Ground-water gradients are generally low throughout most of the plant area, due to the subdued nature of the topography. This fact, coupled with the relatively low permeability of most of the surficial material (10^{-2} to 10^{-7} centimeters per second), results in extremely slow velocities of ground-water flow, on the order of 10^{-1} ft per day.

3.4.5.2 Bedrock Aquifers

At several sites where the surficial material is thin, e.g., K-1064-G, K-1070-F, and K-1004, the water table is generally in the underlying bedrock. As previously discussed, flow directions in the bedrock aquifers, are strongly controlled by the orientation of the bedding planes, fractures, and solution features. The contours of the potentiometric surface (Figure 10) shown on the K-1070-F peninsula, for example, which are based on observed head differences in the bedrock aquifer, can only indicate the general direction of ground-water flow. Deviations in flow due to anisotropy are thought to be highly variable in this aquifer and it is likely that the ground water moves in an angular pattern across the steeply-dipping bedding planes at fractures and then along them in the direction of the regional strike. The flow lines in Figures 7 and 8 indicate schematically the presumed flow routes in bedrock aquifers.

3.4.5.3 Interaquifer Flow

The contours and flow lines of Figure 9 and Figure 10 describe the hydrologic situation in the uppermost aquifer and the bedrock, respectively. At several sites, wells were installed in the bedrock aquifer to determine the head relationship between the two aquifers and the potential for interaquifer flow. At site K-1070-A, for example, the potentiometric surface of the Knox dolostone aquifer was found to be several feet below the water table (see Figure 11). Thus, the potential exists for downward movement of water from the surficial aquifer to the dolostone aquifer. Farther downgradient, toward the area of discharge, the head relation reverses and the potential exists for water to move upward from the dolostone into the surficial aquifer and the Clinch River. At some sites, particularly those underlain by the poorly permeable Rome Formation, it appears that the weathered bedrock aquifer is continuous with the uppermost aquifer. The hydrogeology at each of the sites studied is discussed in Section 5.0, Site-Specific Hydrogeology.

4.0 DRILLING AND DATA COLLECTION

The drilling of test holes, installation of piezometers and monitor wells, and the sampling and testing procedures used in the study were all done in accordance with guidelines developed by Geraghty & Miller, to assure the quality of the work and safety of the workers. These guidelines were contained in two reports submitted to Energy Systems in August and September, 1985. The report "Quality Assurance/Quality Control Plan for the Ground-Water Monitoring Program at the K-25 Plant, Parts 1-3", (Geraghty & Miller, Inc. 1985c) outlined procedures to be followed in the collection and analysis of data. The report "Health and Safety Plan for the RCRA and CERCLA Sites at the K-25 Plant, Oak Ridge, Tennessee" (Geraghty & Miller, Inc. 1985a) described the safety procedures to be used during drilling and data collection activities.

4.1 MONITOR-WELL AND PIEZOMETER DESIGN

Three types of wells were installed during the Phase I, Phase I Extension, Phase II, and Phase II Extension well installation programs at the ORGDP: (1) piezometers completed in unconsolidated material, (2) monitor wells completed in unconsolidated material, and (3) monitor wells completed in bedrock. Piezometers were constructed of 2-inch-diameter PVC casing and screen installed in boreholes augered in the unconsolidated zone to provide information on the thickness, lithology, and hydrology of the unconsolidated material overlying the bedrock. These piezometers were not intended to be used for the purpose of collecting water-quality samples although they can serve that purpose. The same procedures that were used to ensure the integrity of the monitor wells were employed during the installation of the piezometers.

Unconsolidated-zone monitor wells were constructed of 4-inch-diameter stainless steel or PVC casing and screen installed in boreholes augered in the unconsolidated material. Like the piezometers, the unconsolidated zone monitor wells were installed to provide information on the thickness, lithology, and hydrology of the unconsolidated zone. In addition, these wells were constructed in accordance with EPA guidelines (USEPA 1986) on construction of monitor wells for RCRA monitoring so that they could be used to collect representative water-quality samples.

Bedrock monitor wells are similar in design to those in the unconsolidated zone. The major difference is the use of a surface casing to isolate the bedrock zone from the over-lying unconsolidated material thus preventing the possibility of contaminants migrating from one zone to another through the borehole. The bedrock monitor wells were installed to provide information on water quality, hydrology, and lithology of the bedrock without interference from the overlying unconsolidated zones. Bedrock monitor wells were paired with piezometers or unconsolidated monitor wells in selected locations to determine vertical differences in hydraulic head between the unconsolidated zone and the underlying bedrock. Construction diagrams showing details of all wells are included in Appendix C. The details are summarized in Appendix D.

In order to readily distinguish the three types of permanent wells and the zone monitored, a standard prefix has been chosen for each type. The first two letters of the prefix refer to the zone in which the well is screened; "UN" denotes unconsolidated and "BR" denotes bedrock. Monitor wells and piezometers are designated by the letters W and P, respectively, which are the third letters in the prefix. The number following the three-letter combination serves to identify each well of that type as it was installed.

In addition to the above wells, temporary wells were installed as part of an environmental assessment at the K-1414 site. Wells prefixed by "TS" are screened in the unconsolidated zone. Wells prefixed by "TMW" are screened in the bedrock.

4.2 MONITOR-WELL AND PIEZOMETER INSTALLATION

Piezometers UNP-1 through UNP-17, unconsolidated monitor wells UNW-1 through UNW-96, and bedrock monitor wells BRW-1 through BRW-73, were installed at 41 different sites under the supervision of Geraghty & Miller, to gain geologic and hydrologic information. Locations of the piezometers and monitor wells are shown on detailed maps in Appendix A and a discussion of the rationale of well location is provided in the section on Site-Specific Hydrogeology.

The drilling contractor for Phase I of the installation of monitor wells at the ORGDP was Alsay, Inc. Two Failing 1250 rotary drill rigs were used for installation of the bedrock monitor wells and a Diedrich D-50 auger rig was used for installation of piezometers and unconsolidated zone monitor wells. Monitor wells UNW-1 through UNW-7 were installed by Geotek, Inc., using a Mobile B-53 auger rig.

The drilling contractors for Phase II of the installation of the bedrock and unconsolidated monitor wells at the ORGDP were Graves Well Drilling, Inc., and Middle Georgia Water Systems, Inc., respectively. A Dresser T70W air-rotary drill rig was used for the installation of the bedrock zone wells. A Mobile B-53 auger drill rig was used to install the unconsolidated zone wells.

The drilling contractors for Phase I Extension were Middle Georgia Water Systems, Inc., (bedrock zone wells), and Manis Drilling, Inc., (unconsolidated zone wells). An Ingersoll-Rand T4W air-rotary drill rig was used to install the bedrock zone wells and a Mobile B-80 auger drill rig was used to install the unconsolidated zone wells.

The drilling contractor for Phase II Extension was P.D.R. Engineering, Inc. A Schramm T-64 air-rotary drill rig was used to install the bedrock zone wells and a Mobile B-56 auger drill rig was used to install the unconsolidated zone wells.

Temporary unconsolidated zone wells TS-1 through TS-5 were installed by Manis Drilling, Inc. under the supervision of Geraghty & Miller. Temporary bedrock zone wells TMW-1 through TMW-6 were installed by Highland Drilling under the supervision of PEER Consultants, P.C. (PEER, 1989).

Strict adherence to the Quality Assurance/Quality Control (QA/QC) plan issued by Geraghty & Miller (1985c), was maintained throughout the drilling projects to ensure that the permanent wells met all the criteria of RCRA monitor wells. QA/QC measures taken during the drilling program included: thoroughly steam cleaning the drill rigs and all support equipment prior to mobilization on site, steam cleaning as needed during drilling, and steam cleaning of all well casing and screen before insertion into the borehole. A durable ground cover was placed on the ground surface behind the drill rig to control the spread of potentially contaminated soil and rock cuttings. This cover also provided a storage area for drill pipe, casing, bits, and tools to prevent contact with the ground surface. Detailed notes were taken by Geraghty & Miller representatives on site throughout the drilling to provide documentation of each aspect of the well-construction process.

4.2.1 Surficial Aquifer Installations

The boreholes for the piezometers and unconsolidated- zone monitor wells were drilled using a nominal 8- or 9-inch- diameter hollow-stem auger. During drilling of the piezometers, the unconsolidated material was continuously sampled through the auger's hollow stem using a split-spoon sampler. Lithologic descriptions for all piezometers and unconsolidated zone wells are listed in Appendix B.

Upon completion of the Phase I boreholes, schedule 40, flush-joint threaded PVC casing with screen attached was placed in the borehole. Phase II, Phase I Extension, and Phase II Extension wells were completed using stainless-steel screen and casing. Complete well-construction details for individual monitor wells and piezometers are summarized in

Appendix D. Two-inch-diameter casing and screens were used in piezometer construction for economy, and 4-inch-diameter casing and screens were used in monitor-well construction to facilitate sampling. The piezometers were installed using either 5 ft or 10 ft long, 0.01-inch slot screens. The monitor wells have either 5-ft, 10-ft, or 20-ft long screens with either a 0.010-inch, 0.030-inch, or 0.040-inch slot size.

Filter packs of silica sand were placed around the well screens, from the bottom of the hole to approximately 2 ft above the top of the screen. For wells less than 20 ft deep, the sand was poured into the annular space. In deeper wells, the sand was poured through a tremie pipe. A bentonite cap was placed on top of the filter pack to prevent downward seepage of grout into the sand pack. A grout mixture of Type I Portland cement with 5 percent bentonite and a 15.6 lbs/gal slurry weight was used to seal the annulus between the well casing and the borehole above the bentonite cap. For wells less than 20 ft deep, the cement mixture was poured into the annulus, while in the deeper wells a tremie pipe was used.

The piezometers and monitor wells were developed using a submersible pump after the cement had been allowed to set at least 24 hours. Phase I wells were initially developed using the air-lift method; however, supplementary development using a submersible pump was necessary to reduce the turbidity. All other wells were developed with a submersible pump. Development continued until the wells were dry or sediment free. The duration of well development ranged from less than half an hour to 5 hours. A concrete pad to divert rainfall from the well, locking protective casing, and four guard posts to protect the casing were installed at each piezometer and monitor well.

4.2.2 Bedrock Aquifer Installations

Sixty-nine permanent bedrock monitor wells ranging in depth from 23 to 183 ft, were installed at 41 sites during the drilling program. Lithologic descriptions for bedrock monitor wells are listed in Appendix B.

A surface casing was cemented into either a 14 or 15-inch-diameter borehole, drilled using the air or water rotary method, to prevent possible cross contamination from the unconsolidated zone and collapse of the unconsolidated material as drilling progressed. When the cement had set at least 24 hours, a 10-inch-diameter borehole was drilled into the bedrock using air-rotary drilling. In the event that bedrock was at or very near the surface, surface casing was not used.

During Phase I drilling, 4-inch-diameter cores were taken with a core barrel at intervals specified by the site geologist. The cores were to provide information pertaining to the stratigraphy and permeability of the formations. The amount of core taken from the bedrock wells ranged from 7 ft in BRW-1 to 22 ft in BRW-5. When the boreholes for the bedrock monitor wells were completed, or while being advanced into bedrock, bail tests were performed by blowing the borehole dry with air and allowing it to recover. The permeability values obtained from the bail tests ranged from 10^{-6} centimeters per second (cm/sec) in BRW-36 to 10^{-3} cm/sec in BRW-2. For further discussion of bail tests, see Section 4.3, Aquifer Hydraulic Characteristics. When the final depth of the 6-inch-diameter borehole was obtained, and hydraulic testing was completed, the borehole was reamed to 10 inches in diameter using an air hammer.

Upon completion of the Phase I bedrock boreholes, 4-inch-diameter, schedule 40, flush joint threaded PVC casing with screen attached was placed into the hole. Phase I Extension, Phase II, and Phase II Extension wells were completed with 4-inch-diameter, schedule 10, flush joint, threaded, type 316 stainless steel casing with 30-slot, continuous wound screen attached. Complete well-construction details for individual bedrock monitor wells are shown in Appendix C.

A filter pack of silica sand was placed in the annulus using a tremie pipe until the sand pack extended approximately 2 ft above the top of the screen. Bentonite pellets were placed into the annulus on top of the filter pack to prevent downward migration of grout into the sand pack. Type I Portland cement, with a 15.6 lbs/gal slurry weight and 5 percent bentonite, was used to seal the annulus between the well casing and the borehole and was installed using a tremie line. After the cement had been allowed to set at least 24 hours, the bedrock monitor wells were developed using a submersible pump. Development continued until the wells were sediment free. The duration of well development ranged from less than half an hour to 15.2 hours. A cement pad, locking protective casing, and four guard posts were emplaced around each monitor well.

Bedrock Monitor Wells BRW-1, BRW-2, BRW-4, BRW-5, BRW-7, and BRW-8 were geophysically logged by Century Geophysical Corporation. Wells BRW-11 and BRW-12 were logged by Geophysical Consulting Services, Inc., prior to installation of casing and screen. Bedrock Monitor Well BRW-4 was geophysically logged after the installation of casing and screen. Installation of well materials prior to logging was performed because of the tendency of the borehole to collapse. Geophysical logs were used in conjunction with drill cuttings and core to characterize the lithology and hydrology of the boreholes.

4.3 AQUIFER HYDRAULIC CHARACTERISTICS

Single-well tests were conducted on Phase I bedrock boreholes as they were advanced. A number of completed wells and completed piezometers were also tested to determine values of permeability. The tests were performed by rapidly adding or removing a known volume of water and measuring the response of the water level over time. The advantages of such tests are that they can be completed in a relatively short time and yield reliable permeability values. The disadvantage of short-term tests is that the permeability values obtained apply only to a small portion of the aquifer, immediately adjacent to the well, and cannot be applied over a large area. The tests were analyzed using two methods developed by Bouwer and Rice (1976) and Hvorslev (1951). Permeability values for the unconsolidated zone range from 10^{-7} to 10^{-2} cm/sec. Bedrock permeability values range from 10^{-6} to 10^{-3} cm/sec. Permeability values for wells and piezometers are presented in Table 1.

During the late spring and summer of 1981, Geraghty & Miller conducted a series of multiple-well pump tests on property directly across the Clinch River from site K-770 (Geraghty & Miller, Inc. 1981). These tests were conducted in conjunction with a site investigation unrelated to that at the ORGDP. Transmissivity values for the bedrock underlying the site (Upper Rome Formation, Chickamauga, and Knox Groups) ranged from 22 to 15,000 gallons per day per foot (gpd/ft) with most values ranging from 22 to 600 gpd/ft. Specific capacity values ranged from 0.053 to 21.6 gallons per minute per foot of drawdown. Due to the heterogeneity of bedrock in the region, these test results may or may not be representative of hydraulic conditions present within the plant boundaries.

Table 1. Results of Permeability Tests

Boring Number	Location	Method of Analysis Bouwer (cm/sec)	Hvorslev (cm/sec)
UNP-1	K-1070-C,D	5.34×10^{-6}	7.04×10^{-6}
UNP-2	K-1070-C,D	5.77×10^{-7}	6.15×10^{-7}
UNP-3	K-1070-B	5.40×10^{-6}	1.66×10^{-5}
UNP-4	K-1070-B	2.79×10^{-6}	8.19×10^{-6}
UNP-5	K-1070-B	3.23×10^{-6}	4.28×10^{-6}
UNP-6	K-1085	2.48×10^{-2}	1.95×10^{-2}
UNP-7	K-1232	4.92×10^{-6}	4.11×10^{-6}
UNP-8	K-1413	8.30×10^{-5}	8.73×10^{-5}
UNP-9	K-770	1.33×10^{-5}	9.57×10^{-6}
UNP-10	K-770	3.08×10^{-4}	3.57×10^{-4}
UNP-11	K-1085	6.05×10^{-5}	6.90×10^{-5}
UNP-12	K-1070-A	1.10×10^{-6}	1.04×10^{-6}
UNP-13	K-1070-C,D	2.20×10^{-5}	1.08×10^{-5}
UNP-14	K-1070-A	1.21×10^{-6}	1.08×10^{-6}
UNP-15	K-1070-A	2.71×10^{-7}	2.94×10^{-7}
UNP-16	K-770	1.05×10^{-5}	7.80×10^{-6}
UNP-17	K-1070-C,D	2.60×10^{-4}	8.10×10^{-3}
UNW-1	K-1407-B	3.56×10^{-4}	4.21×10^{-4}
UNW-2	K-1407-B	1.44×10^{-4}	6.11×10^{-4}
UNW-3	K-1407-B	2.33×10^{-4}	4.83×10^{-4}
UNW-4	K-1407-B	1.08×10^{-4}	4.01×10^{-4}
UNW-5	K-1407-B	2.38×10^{-4}	2.16×10^{-4}
UNW-6	K-1407-C	3.72×10^{-5}	3.47×10^{-5}
UNW-7	K-1407-C	1.08×10^{-3}	6.51×10^{-3}
UNW-8	K-1407-C	1.01×10^{-4}	3.60×10^{-4}
UNW-9	K-1407-C	2.56×10^{-4}	8.23×10^{-4}
UNW-10	K-1407-C	1.06×10^{-3}	3.08×10^{-3}
UNW-11	K-1407-C	5.43×10^{-7}	2.51×10^{-7}
UNW-37	K-27	2×10^{-3}	
UNW-38	K-27	6×10^{-3}	
UNW-46	K-901-A	1×10^{-6}	
UNW-47	K-1004	4×10^{-5}	
UNW-57	K-720	1×10^{-5}	
BRW-1	K-1099	1.34×10^{-3}	
BRW-2	K-1064-G	1.54×10^{-3}	
BRW-3	K-1064-G	5.27×10^{-3}	
BRW-5	K-1070-A	5.02×10^{-5}	
BRW-6	K-1070-A	2.03×10^{-4}	
BRW-7	K-1407-B	3.58×10^{-5}	
BRW-8	K-1070-B	6.71×10^{-5}	
BRW-23	K-1070-F	2×10^{-5}	
BRW-27	K-33	2×10^{-4}	
BRW-34	K-901-A	1×10^{-3}	
BRW-36	K-1004	5×10^{-6}	
BRW-38	K-1004-L	2×10^{-4}	
BRW-46	K-1414	4×10^{-5}	

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5.0 SITE-SPECIFIC HYDROGEOLOGY

Test holes were drilled in the vicinity of the various waste-management sites, as judged necessary to obtain an understanding of the hydrogeology at the site. Location of the test wells and piezometers are shown on the site maps in Appendix A, along with pertinent hydrogeologic information. Well-construction diagrams of unconsolidated zone Wells UNW-1 to UNW-96, bedrock wells BRW-1 to BRW-73, and temporary wells TS-1 to TS-5 and TMW-1 to TMW-6 are included in Appendix C. Cutting samples from material penetrated by the drill or auger were carefully examined and described in the well logs of Appendix B. Results of permeability tests on monitor wells and piezometers are listed in Table 1. Details of well construction are summarized in Appendix D. Hydrographs showing fluctuations of water levels in the wells and piezometers for the period of record comprise Appendix E. Water level depths and elevations are presented in Appendix F. These data were analyzed and applied toward interpretation of the hydrogeology of each of the waste-management sites as discussed in the following sections.

5.1 SITE K-1232 TREATMENT FACILITY

The area of interest at K-1232 contains four open-top, in-ground concrete tanks used to store liquid waste that, although treated, may be corrosive, EP toxic and listed by definition as per Resource Conservation and Recovery Act (RCRA) regulations found in 40 CFR 261. The tanks are at the top of a bluff, about 50 ft above and 150 ft south of Poplar Creek (Figure 2).

Six wells, UNP-7, UNW-28, UNW-29, UNW-30, BRW-16 and BRW-41, (Figures A-1 and A-2), were drilled at this site. The permeability of the clay as determined by a slug test of UNP-7, was found to be 10^{-6} cm/sec.

The concrete rim of the two main tanks is at an altitude of 788 ft msl. The treated liquid generally stands a foot or two below that. Water levels in wells at the site fluctuate as shown in Figure E-1. Stage of Poplar Creek during this period of record ranged from 736.2 to 738.2 ft msl. Thus, ground water flows along a very steep gradient from the tank area to the creek.

Most likely ground water in the underlying Chickamauga Group bedrock also flows along a steep gradient to the creek. The potentiometric surface in the limestone is below that in the residuum indicating that the bedrock receives leakage from the overlying residuum at this site.

5.2 SITES K-1070-B CONTAMINATED BURIAL GROUND K-1407-A NEUTRALIZATION FACILITY, K-1407-SETTLEMENT POND, K-1407-C RETENTION POND, AND K-1700 WATERSHED

K-1070-B, the Contaminated Burial Ground, is considered here along with RCRA sites K-1407-A, K-1407-B, and K-1407-C because of their proximity. The sites occupy a small 420 acre valley, the K-1700 Watershed, that drains the northeastern corner of the plant in a westerly direction then north to Poplar Creek via Mitchell Creek (Figure A-3). Prior to November 8, 1988, discharge of the stream was principally effluent from K-1407-B Pond. The pond was subsequently removed from service and drained as part of a RCRA closure. Discharge of the stream presently consists of effluent from treatment of coal pile runoff at the Central Neutralization Facility, storm drains that may extend beyond the topographic boundaries of the valley, and the natural runoff and ground-water seepage from the valley itself. Some of this drainage may be diverted by storm drains to outlets beyond the K-1700 Watershed. Downgradient from the sites, surface runoff, along with storm drains from other parts of the plant and considerable ground-water effluent, is collected into a subsurface drain, and flows through NPDES station 1700, which monitors the pH of the water.

Eighteen monitor wells and three piezometers have been installed in the unconsolidated aquifer and four monitor wells installed in the bedrock aquifer in the vicinity of the K-1700 Watershed (Figures A-3 and A-4). Construction diagrams and lithologic logs of the wells and piezometers are included in Appendices B and C. Permeability values for selected wells and piezometers are reported in Table 1.

Depth of penetration of the shallow wells suggests a relatively thin cover of unconsolidated material ranging in thickness from 11 to 40 ft. The cover appears to be thin along the axis of the valley and deeper on the hillsides to the north and south. The cover is comprised largely of residuum of the underlying rock, principally clay with occasional inclusions of weathered bedrock. Chert fragments are most common and, in association with red clay matrix, suggest a carbonate bedrock origin at wells UNW-1, UNW-4, UNW-6, and UNW-11. Weathered shale fragments were recovered from wells UNW-4, UNW-5, and UNW-10 in association with gray and brown clay. Importation of fill is indicated by several of the well logs and may account, in part, for the erratic distribution of unconsolidated material. Wells BRW-7 and BRW-8 both penetrated limestone and shale beneath fill material. The distribution of different rock types suggests complex bedrock geology that may be due to the faults that trend through the area (Figure 6).

Permeability of the unconsolidated material ranges from 10^{-7} to 10^{-3} cm/sec. Most of the tests, however, produced values of permeability in the 10^{-5} to 10^{-4} cm/sec range. Values of permeability of bedrock wells BRW-7 and BRW-8 were 10^{-4} and 10^{-5} cm/sec. Contours on the water table of the unconsolidated aquifer are shown in Figure A-3 for August 23, 1989.

Ground-water flow through the upper aquifer is normal to the contours, from the hillsides toward the valley, where it discharges to Mitchell Creek. Under present conditions, much of the ground water discharges to the storm drain system, thence through NPDES 1700 to Poplar Creek. It appears that ground-water flow at the K-1407-B Pond is influenced by the construction of the pond and the elevation of the pond outfall to Mitchell Creek. Hydrographs for the period of record for the monitor wells and piezometers are plotted on Figures E-2 to E-5 in Appendix E.

Bedrock wells, BRW-7, BRW-8, BRW-13 and BRW-14 are paired with shallow water-table wells UNW-3, UNP-3, UNW-11 and UNW-10, respectively. Water levels in the bedrock wells closely correspond to those in the shallow wells with which they are paired and the data indicate reversals in the direction of the vertical gradient do occur. The fact that higher heads sometimes occur in the underlying limestone aquifer indicates the potential exists for upward leakage of water from the limestone to the uppermost aquifer which may retard the downward migration of dissolved contaminants.

5.3 SITE K-1413 TREATMENT FACILITY, PROCESS LINES, NORTH SUMP, AND EAST SUMP

The K-1413 Treatment Facility is located on a terrace near the center of the ORGDP as shown in Figure 2. The facility is a 15 ft deep, 20,000 gallon, in-ground concrete tank used to neutralize and precipitate metal-laden waste. Associated with the facility are two sumps (North Sump and East Sump) and a number of vitreous-clay process lines which connect them to the K-1407-A Neutralization Pit. The capacity of the two sumps is about 500 to 1,000 gallons each. These waste-management units are being addressed together due to their common association and proximity to the K-1413 Treatment Facility.

Five monitor wells (UNW-26, UNW-27, UNW-55, UNW-89, and UNW-90) and one piezometer (UNP-8) were installed in the unconsolidated residuum at these sites (Figure A-5). The overburden consists of clay with fragments of weathered shale, chert and limestone underlain by weathered shale. Permeability of the weathered shale was found to be 10^{-4} cm/sec. This is more permeable than either the shale bedrock or shale residuum values, reported in Table 1, suggesting a path of preferred ground-water flow within the zone of weathered shale. The hydrograph (Figure E-6) shows a range of ground-water fluctuation that appears to be above the bottom of the K-1413 tank during much of the year.

One monitor well, BRW-15, was constructed in the bedrock aquifer. Lithologic logs indicate 30 ft of clay and 8 ft of weathered shale underlain by limestone. Ground-water levels at the site indicate an upward vertical gradient between the unconsolidated zone and the bedrock. Water levels in BRW-15 are consistently higher than those in the adjacent unconsolidated-zone wells UNW-26, UNW-27, UNW-54, and UNP-8.

Ground-water measurements from the unconsolidated-zone wells and piezometer indicate a slight hydraulic gradient to the northeast (Figure A-5), however, natural hydrogeologic conditions have been altered in this area by the effects of industrialization. Pavement and roofs intercept rainfall, routing the water to storm drains and limiting natural recharge to the water table. Storm drains may leak water to the uppermost aquifer or drain it, depending on whether the drain lies above or below the water table. Most drains and pipes are laid in a bed of graded gravel which may form permeable channels for ground-water flow that disrupt the natural regimen and complicate attempts to analyze the system.

5.4 SITE K-1070-C AND D CLASSIFIED BURIAL GROUND

The Classified Burial Ground occupies a hilltop in the southeastern corner of the plant. The hill is underlain by siltstone, sandstone, shale, and carbonates of the Rome Formation. It is bounded on the west by a north-trending fault (Figure 6) that plunges easterly, at a relatively low angle beneath the site (Figure 8). Surface runoff drains the hilltop in all directions to the plant storm-drain system and eventually to Poplar Creek.

Nine shallow test holes were drilled at this site (Figures A-6 and A-7). The wells and piezometers penetrate clay and weathered siltstone or silty-shale to depths ranging from 14.5 to 39 ft. Slug tests conducted in two of the piezometers, UNP-1 and UNP-13, indicated a permeability of about 10^{-5} cm/sec. A third test, conducted in UNP-2, indicated a permeability of 10^{-6} cm/sec. Hydrographs for wells at the site are presented in Figure E-8.

Wells BRW-9 and BRW-12 were drilled through clay residuum and penetrated dolostone and limestone, as well as siltstone and shale from about 30 ft to the total depths of 123 and 300 ft respectively. No permeability tests were conducted at either well. BRW-9 was pumped dry during development and recovered so slowly during the following two weeks that permeability is presumed to be extremely low. The water level in BRW-9 now stands well above levels in the shallow wells. This may not be an indication of vertical head difference between the bedrock and residuum aquifers but may simply be due to the fact that BRW-9 taps the water table at the highest point on the hilltop. BRW-11, located on the west flank of the hill, was drilled through the fault between the sandy siltstone of the Upper Rome and limestone of the underlying Chickamauga Group. No water was noted at the contact, indicating that the fault may be sealed by secondary mineralization. Well BRW-10, located a few hundred feet southeast of BRW-11, was drilled entirely in the Chickamauga indicating that the fault trace surfaces between the two wells.

Ground water is presumed to move through the unconsolidated residuum that blankets the hilltop site of K-1070-C, D, down the slopes, in a radial flow pattern. Several ephemeral springs are reported at the break in slope where the hillside becomes less steep and merges with the plain on which the plant is situated. Ground-water levels from well clusters BRW-10/UNW-17 and BRW-11/UNW-18 show a pronounced downward vertical gradient between the unconsolidated zone and the bedrock. Well cluster BRW-12/UNW-19 shows approximately equal heads between the unconsolidated zone and the bedrock.

5.5 SITE K-1099 BLAIR ROAD QUARRY

The Blair Road Quarry was used for burning radioactive- contaminated paper and wood in a large metal pan prior to 1970. The quarry is cut into the west end of east-trending McKinney Ridge. An area of about three acres drains internally to the quarry floor. Evidence of ponding is slight, suggesting that downward infiltration of rainfall is relatively unimpeded by the rubble and dolostone that comprise the quarry floor. Natural permeability of the rock may have been enhanced by blasting of shot holes in the quarrying operation.

A large fault is exposed in the dolostone face of the quarry and trends easterly along the crest of McKinney Ridge. No evidence of water seeping from the fault is apparent in the quarry face, nor in the immediate vicinity of the fault. Along the north and south highwalls of the quarry, however, fractures and weathering along bedding planes become more pronounced and the potential for ground-water movement appears much greater than in the immediate vicinity of the fault.

One monitor well was installed in the quarry (Figure A-8), to a total depth of 47 ft. Calcite-filled fractures noted in the lithologic log (Appendix B), were numerous. From 40 to 47 ft a 6-inch- diameter core was taken. Examination of the core shows very few fractures, and those are generally filled with calcite. Breaks in the core, caused by the drilling or handling appear to follow natural fractures, but no evidence for ground-water movement such as mineral stains or corrosion of the surfaces was apparent.

In spite of the lack of visual evidence of secondary permeability, the borehole made water at about 29 ft, and subsequent tests indicated a permeability of 10^{-3} cm/sec. A hydrograph for monitor well BRW-1 is presented in Figure E-9. The wide flucuations in the water level are a result of rapid recharge and subsequent discharge caused by rainfall events.

5.6 SITE K-770 SCRAP-METAL YARD

The Scrap-Metal Yard is located along a meander bend of the Clinch River upstream from the confluence with Poplar Creek (Figure 2). The site was used for surface storage of radioactive-contaminated scrap metal. Other known contaminants include PCBs, mercury, and asbestos incidental to scrap-metal operations that were stored prior to initiation of a waste-management tracking program in 1977. Surface runoff drains from a hillside at the eastern side of the site toward the north and west to the Clinch River. A drainage ditch parallels the railroad tracks, in the northern part of the site, collecting water from that relatively low area for discharge to the Clinch River. Several large-diameter pipes extend from the riverbank below the scrapyard fence. No construction details are available, but it seems likely the pipes are part of a drain field designed to dewater the scrap-metal yard.

Three 2-inch piezometers and four 4-inch wells were constructed to monitor shallow ground-water conditions at the scrap-metal yard. Piezometer UNP-16 is located upgradient from the yard and should be effective for monitoring background conditions. Piezometer UNP-9 and wells UNW-12 and UNW-13 are set along the northwest boundary, and UNW-14 and UNW-15 are set along the western boundary near the bank of Clinch River, and are designed to monitor shallow ground-water flow from the scrap yard to the river (Figure A-9).

The test wells were augered into fluvial deposits to depths of 30 to 39 ft. The sediments consist of well-sorted, well-rounded, fine-grained sand with some clay. Depth of the Clinch River in this reach is reportedly 30 ft below normal stage of 741 ft msl. The river bed is cut into bedrock and the six downgradient wells apparently penetrate the entire section of fluvial sediments. The scrap-metal yard has the appearance of a floodplain or terrace, although some of the area has probably been graded, to some extent, during the period of use. Results of the permeability tests indicate values of 10^{-5} cm/sec at UNP-9 and 10^{-4} cm/sec at UNP-10. The difference is likely due to variations in clay content in the fluvial deposits.

Water levels in the wells confirm that shallow ground water flows from the upland site at UNP-16 toward the river (Figure A-9). Water levels in UNP-16, in the upland recharge area, fluctuate vigorously in response to rainfall (Figure E-10). Water levels in UNP-9, UNP-10, and UNW-12 through UNW-15, however, are relatively subdued, due to their proximity to Clinch River which is the line of ground-water discharge. The water table beneath the K-770 floodplain is relatively flat, due to the flat topography and the proximity of the Clinch River and possibly to the presence of a drain field beneath the site. Local recharge to the uppermost aquifer at K-770 moves laterally to discharge into the Clinch River. During high stages of the river, it is possible that ground-water flow may be halted or temporarily reversed.

5.7 SITE K-1064-G PENINSULA STORAGE AND BURN AREA

The peninsula storage and burn area is located within the plant on a peninsula that extends northward into a meander of Poplar Creek about three miles above its confluence with Clinch River. The site was used for storage of drums containing oils and solvents. Some waste was burned in an open steel pan. The site was closed prior to 1980.

The peninsula stands about 40 ft above Poplar Creek at its normal stage of 740 ft msl. The Chickamauga limestone is generally mantled by less than 5 ft of fill or clay residuum on the peninsula and is exposed along the creek bed. The limestone is thin-bedded, with intercalations of shale that weather to clay causing expansion of the bedding planes and permitting relatively rapid movement of ground water which in turn promotes further weathering. The limestone beds strike roughly northeast, the regional orientation, and dip south-eastward at varying angles.

Seven bedrock wells were drilled at the site (Figure A-10). BRW-2, BRW-3, BRW-17, and BRW-20 were finished in limestone at 35 to 65 ft total depths. BRW-4 penetrated 75 ft of shale, slightly calcareous, with only occasional slight traces of limestone present. BRW-18 and BRW-19 penetrated a 10 to 15 ft thick stratum composed primarily of limestone intercalated with traces of shale, underlain of strata of shale intercalated with traces of limestone. Lithologic logs (Appendix B) show that all four limestone wells intercepted cavities in the rock. Permeability values (Table 1) were 10^{-3} cm/sec at well BRW-2 and 10^{-2} cm/sec at BRW-3.

Ground-water flucuations in wells BRW-2, BRW-1, and BRW-17 through BRW-20 generally parallel each other, suggesting that the hydraulic properties of the screened intervals in these wells are similar. Well BRW-4 was pumped dry during development on January 27, 1986. As can be seen in the hydrograph presented in Figure

E-11, BRW-4 has shown no recovery response since that time, indicating that the shale beds within the screened interval are essentially impermeable.

Data suggests that ground-water movement is largely along bedding planes and cavities in the limestone. Local recharge moves downward to the water table then laterally to Poplar Creek. The presence of shale beds, such as those intercepted in well BRW-4, may restrict ground-water movement across bedding and serve to enhance the flow to the northeast and southwest.

5.8 SITE K-1085 FIREHOUSE BURN AREA

The Firehouse Burn Area, K-1085, was used prior to 1970 for burning oils, paints, and solvents in metal pans on concrete pads. The site is located southwest of the plant property (Figure 2) and is bounded in triangular fashion by Powerhouse Road to the north, Bear Creek Road to the south, and Oak Ridge Turnpike to the east (Figure A-11). Poplar Creek makes its final meander 300 ft north of the site, to its confluence with the Clinch River. The K-1085 site lies near the crest of a gentle, east-trending topographic divide. Surface runoff flows in a northerly direction from the divide to Poplar Creek, about 300 ft north. South of the divide, the land surface slopes more gently to the Clinch River, about 1,600 ft to the south.

Two 2-inch piezometers and three 4-inch unconsolidated zone wells were installed at the site. The depths of these piezometers and wells ranged from 31 to 51 ft below land surface. The unconsolidated materials encountered in the boreholes consisted of reddish brown, slightly silty clays with mottled yellow, tan, and dark brown layers. Relict bedrock structures are preserved in the lower portions of the residuum.

Slug tests conducted on the piezometers yielded permeability values of 10^{-4} cm/sec at UNP-11 and 10^{-2} cm/sec at UNP-6. Relict bedrock structure was observed in the samples from UNP-6 and may be responsible for its relatively high permeability. Ground-water elevations indicate that ground-water flow primarily trends toward Poplar Creek to the north of the site. Hydrographs for wells at the site are shown in Figure E-13.

The Whiteoak Mountain thrust fault trends northeasterly across the northwest corner of the site, but present data do not permit interpretation of whether the fault has any effect on ground-water conditions.

5.9 SITE K-1070-A CONTAMINATED BURIAL GROUND

The contaminated Burial Ground lies on the southeast slope of Blackoak Ridge, north of West Perimeter Road, north of ORGDP (Figure 2). The site was used for disposal of radioactive and RCRA mixed-chemical wastes prior to 1975.

The ridge is underlain by dolostone of the Knox Group. Much of the section is exposed in the gap through which Poplar Creek flows, about 1.5 miles northeast of the site. The rocks exposed are thick-bedded dolostones with well-developed weathering along bedding planes and fractures parallel to the dip. Contact with the overlying residuum is highly irregular because of selective weathering of the bedrock surface.

Five shallow wells were augered in the overburden and four wells drilled into rock as shown in Figures A-12 and A-13. Wells set in the unconsolidated residuum ranged in depth from 42 to 58 ft. Overburden at all the shallow wells is reddish, plastic clay with numerous nodules of chert; typical residuum of the Knox Group. Depth to the water table in the overburden, which constitutes the uppermost aquifer, ranges from 28 to 45 ft, and the ground-water gradient is subparallel to the land surface, sloping southeastward at about 12 ft per 100 ft (Figure 11). Permeability of the residual clays, as determined by slug tests of each of the piezometers, ranged from 10^{-6} to 10^{-7} cm/sec.

Four wells (BRW-5, BRW-6, BRW-25, and BRW-26) were drilled by the air-rotary method into the bedrock aquifer. Core was recovered from well BRW-5 from most of the interval from 70 to 91 ft. The core showed a dense rock with occasional partings, dipping from about 45 degrees, with some solution development. Recrystallized calcite and iron-oxide stain indicate previous movement of ground water along some of the partings.

BRW-6, also drilled to a total depth of 100 ft was not cored, but intersected mud-filled cavities at depths from 70 to 73 ft and 87 to 93 ft. BRW-25 and BRW-26 were drilled to depths of 92 and 84 ft, respectively. BRW-25 produced approximately 10 gallons per minute (gpm) from a solution cavity at 77 to 79.5 ft; BRW-26 produced < 1 gpm from a cavity at 68 ft. Permeability of the dolostone aquifer was found to be 10^{-4} cm/sec at both BRW-5 and BRW-6. Permeability of the bedrock is due more to the fractures and solution cavities than to the primary porosity of the rock itself, which is quite dense.

Permeability of the bedrock aquifer is about two orders of magnitude greater than that of the clay residuum. The relationship of the water table in the unconsolidated aquifer to the potentiometric surface in the dolostone aquifer is shown in Figures 11, A-12, A-13 and E-14. Although the hydrogeologic section of Figure 11 shows a general decline in head of both aquifers following the topography, actual movement in the upper aquifer is vertically downward into the dolostone aquifer. The head difference between the two aquifers is least at the site of UNW-31 and BRW-25 and reverses between these wells and BRW-26 and UNW-32. The cavities are filled with a mud-water mixture, not the dense plastic clay described in the upper aquifer. Thus, downward movement of water is facilitated, causing a decrease in the head difference between the two aquifers at the site.

Data from wells throughout the Valley and Ridge Province consistently show that fractures and solution openings diminish with depth, both in frequency and size. Ground-water movement through the dolostone aquifer, therefore, follows flow lines perpendicular to the contours, down- gradient toward the Clinch River. Actual flow paths controlled by the solutionally-enlarged fractures, joints and bedding planes are more irregular than the contours on the potentiometric surface suggest. Probable flow paths along bedding planes and fractures are suggested by the flow lines in Figure 11.

It is apparent that any contaminant plume will have been carried downward into the dolostone aquifer and along the irregular flow paths, in a generally down-gradient direction. Lateral movement within the uppermost aquifer is inferred to be two orders of magnitude slower, because of the less permeable unconsolidated residuum.

5.10 SITE K-1070-F CONTRACTORS BURIAL GROUND

K-1070-F site is bounded to the east, south, and west by a meander bend of Poplar Creek. The confluence of Poplar Creek with the Clinch River is located at the northwest corner of the site (Figures 2 and A-14). Topography is hilly to rolling along the crest of the peninsula with steep slopes down to stream level. Available records indicate this site was used for burial of waste construction material. TDHE suggested that further investigation was warranted due to the lack of documentation.

An extensive boring program was conducted at K-1070-F in 1984 by Energy Systems (Barton, pers. comm. 1985). Forty-five 8-inch auger holes were drilled in a grid pattern on 150-ft centers. Bedrock cores were taken from five of the holes. In addition to these holes, Geraghty & Miller has installed five monitor wells (BRW-21 through BRW-24 and BRW-40) in the bedrock at this site (Figure A-14).

The depth to bedrock at the site ranges from 12 to 68.5 ft. Average depth to bedrock is approximately 25 ft. Over-burden thickness is greatest along a bedrock low that trends from the center of the site, easterly toward Poplar Creek. Depth to bedrock over the rest of the site approximately parallels topography.

Overburden at the site consists of fill material, red-brown to tan to brown silty clay with chert fragments, and weathered brown shale. Fill material ranges in thickness from 0 to 20 ft and consists partially of concrete, wood, and metal.

K-1070-F site is underlain by bedrock of the Chickamauga limestone. Lithologic logs from the coreholes and monitor wells contain descriptions of the upper bedrock as medium to dark gray, fine to medium-grained, cavernous and fractured limestone with thin shale partings, and chert nodules. Bedding in the cores had dips ranging from 10 to 20 degrees. Exposures along the Clinch River show the bedding ranges from vertical to horizontal over short distances due to the folding and fracturing.

Water-level data available suggests that infiltration moves downward to the underlying limestone, then along bedding planes in a northeasterly and southwesterly direction to discharge into Poplar Creek or Clinch River (Figure A-14). The permeability of the bedrock, as determined by slug test data from BRW-23, is on the order of 10^{-5} cm/sec. This well, however, was not screened in a cavity which would be expected to have a much greater permeability (i.e., 3 or 4 orders of magnitude). Hydrographs for wells at the site are shown in Figure E-15.

5.11 K-802-H AND K-802-B COOLING TOWER BASINS

The K-802-H and K-802-B Cooling Tower Basins are located within the plant 700 ft northwest of the K-25 Building in the peninsula storage area (Figure A-15). The K-802-H facility is a 430 x 60 x 15 ft concrete, in-ground recirculating cooling water (RCW) basin with a 5.8 million-gallon (MG) capacity. The RCW received a treatment to maintain concentrations of 18-22 ppm chromium, 1-2 ppm zinc and 0.8-1.6 ppm phosphorus. The K-802-B facility is located within the plant, 700 ft northwest of the K-25 Building and 150 ft east of Poplar Creek. The facility is a 340 x 65 x 15 ft, 2.4 MG, concrete, in-ground, RCW basin. The RCW received a non-chromium, phosphate-zinc treatment; however, hazardous constituents are suspected to be present.

Five bedrock wells (BRW-29, BRW-37 and BRW-59 through BRW-61) were drilled at the site (Figure A-15). Each of these wells were completed in rocks of the Chickamauga Group which consisted primarily of limestone with interbeds of shale. Each well encountered water-producing fracture zones at depths of less than 40 ft. Ground-water elevations determined on August 23, 1989, indicate flow trends eastward and westward from the basins toward Poplar Creek, which has a normal stage of 740 ft msl. Figure E-16 presents the hydrographs for these wells for the period of record. Available information indicates the bottom of the basins lie at approximately the same elevation as the potentiometric surface in this area.

5.12 K-832-H COOLING TOWER BASIN

The K-832-H Cooling Tower Basin is located within the plant 550 ft west of the K-27 Building and 270 ft east of Poplar Creek (Figure 2). The facility is a 350 x 65 x 13 ft, concrete, in-ground RCW basin with a 2.8 MG capacity. The RCW received a chromate, zinc, and phosphate treatment.

Three unconsolidated zone wells, UNW-41 located on the west flank of the facility, UNW-42 located on the east flank, and UNW-85 located at the southeast corner, were augered to refusal. One bedrock zone well, BRW-57, was constructed adjacent to UNW-41 (Figure A-17). The overburden material consists of a red to brown, silty clay containing fragments of weathered limestone. Bedrock under the site consists of micritic limestone of the Chickamauga Group. Ground-water elevations indicate ground-water flow in the unconsolidated zone trends southwest across the site towards Poplar Creek (Figure A-16). Available construction information for the basin indicates the elevation of the bottom slab approximately corresponds to the elevation of the water table in this area.

5.13 K-862-E COOLING TOWER BASIN

The K-862-E Cooling Tower Basin is located 280 ft east of the K-31 Building, 650 ft west of Poplar Creek (Figure 2). The facility is a 385 x 63 x 16 ft, 4.5 MG capacity, concrete, in-ground, RCW storage tank. The RCW received a chromate, zinc, and phosphate treatment.

Unconsolidated zone monitor wells UNW-43, UNW-81, and UNW-82 were paired with bedrock wells BRW-30, BRW-65, and BRW-64, respectively. The lithologic logs from these borings indicate 27 to 36.5 ft of orange-brown and red-brown, silty clay underlain by cavernous limestone of the Chickamauga Group.

Available ground-water data from the three well clusters at the site indicate the elevation of the potentiometric surface within the shallow bedrock corresponds to the elevation of the water table in the unconsolidated zone at this site (Figure E-18). Lateral ground-water flow is from the site towards Poplar Creek, to the south and east (Figures A-18 and A-19).

5.14 K-892-G/H COOLING TOWER BASIN

The K-892-G/H Cooling Tower Basin is located in the northwestern part of the plant, 400 ft east of the K-33 Building and 250 ft west of Poplar Creek (Figure 2). The facility is a 950 x 65 x 28 ft, concrete, in-ground, RCW storage tank. The RCW received a chromate, zinc, and phosophate treatment.

Unconsolidated zone monitor wells UNW-44 and UNW-83 were paired with bedrock wells BRW-31 and BRW-63, respectively. The lithologic logs from these borings indicate 23 to 42 ft of light-brown and red silty clay underlain by interbedded limestone and shale of the Chickamauga Group.

Comparison of available water-level data for the bedrock wells to construction information indicates the potentiometric surface lies approximately 20 to 30 ft below the bottom slab of the basins and approximately 5 to 10 ft below any associated piping. Lateral ground-water flow in the bedrock is inferred to be to the east toward Poplar Creek (Figures A-18 and A-19). Hydrographs for wells at the site are shown in Figure E-19.

5.15 K-892-J COOLING TOWER BASIN

The K-892-J Cooling Tower Basin is located in the northwest part of the plant, 400 ft north of the K-33 Building and 425 ft west of the Poplar Creek (Figure 2). The facility is a 320 x 40 x 4 ft, 200,00 gallon capacity, concrete, in-ground, RCW storage tank. The RCW received a chromate, zinc, and phosphate treatment.

Two unconsolidated zone monitor wells, UNW-45 and UNW-78, were constructed at the site. One bedrock well, BRW-32, was paired with UNW-45. Lithologic logs from UNW-45/BRW-32 indicate that the bedrock surface in this area is highly irregular. The two paired boreholes are approximately 15 ft apart horizontally, however, bedrock was encountered at 33 ft in BRW-32 and at 57 ft in UNW-45. The unconsolidated residuum consists of orange-brown, slightly silty clay containing fragments of chert and limestone. The bedrock consists of interbedded dolostone and limestone of the Knox Group. No significant solution cavities were encountered in the bedrock; however, a water-producing fracture zone was present at 106 ft below ground surface.

Available ground-water data indicate reversals of the vertical hydraulic gradient may occur between the bedrock and the unconsolidated zone at this location (Figure E-20); however, the downward movement of contaminants is probably limited by the presence of a prominant surface drainage feature nearby which is the most likely destination of a contaminant plume. Lateral ground-water flow is to the east towards Poplar Creek and also to the south, then east to the creek (Figures A-18 and A-19). Comparison of construction information to the water level data indicates the bottom slab of the basin lies over 50 ft above the water table and the associated piping lies from 25 ft to 50 ft above the water table.

5.16 K-1007 UNDERGROUND GASOLINE STORAGE TANK

The K-1007 Underground Gasoline Storage Tank, which was removed in 1986, was located outside the plant, just north of the K-1007 Building (Figure 2). The 250 gallon tank was buried 6 to 8 ft below ground. Gasoline was observed in the soil surrounding the tank at the time it was excavated.

In an effort to determine the lateral extent of ground-water contamination, three unconsolidated zone wells, UNW-70 through UNW-72, were constructed at the site. The lithology at the site consists of 4 to 16 ft of silty variegated clay underlain by interbedded limestone and shale.

Available ground-water level data from these wells and from wells at adjacent sites indicate that lateral ground-water flow at K-1007 is to the southwest, towards the K-1007-B Holding Pond and Poplar Creek (Figure A-20). The well cluster BRW-36/UNW-47, a short distance to the north of the site, indicates a slight upward vertical gradient exists between the bedrock and the unconsolidated zone during some periods indicating the likelihood that ground water in the bedrock is discharged to the K-1007-B Pond. Hydrographs for the three unconsolidated zone wells at the site are presented in Figure E-21.

5.17 K-1401 DEGREASER TANKS

The K-1401 Degreaser Tanks are stainless-steel tanks placed in bricklined pits within a large concrete structure inside the K-1401 Building in the northeastern part of the plant (Figure 2). These tanks contain trichloroethane into which equipment is lowered for degreasing.

Two shallow monitor wells, UNW-53 and UNW-91, were augered in the overburden to depths of 23.5 ft and 28.0 ft, respectively. The thickness of the unconsolidated material at other nearby well locations (UNW-51 and UNW-52) ranged from 18.5 to 33 ft. The unconsolidated material consists of silty, brown clay with fragments of weathered gray shale. One bedrock well (UNW-49) was constructed adjacent to UNW-53. Bedrock at the site consists of silty shale underlain by micritic and oolitic limestone. Ground-water level data from these wells and from wells at adjacent sites indicate that lateral ground-water flow in both the bedrock and the unconsolidated zone is to the north and northwest, towards Mitchell Creek (Figures A-22 and A-23). Preliminary ground-water level data from the well cluster BRW-49/UNW-53 indicate that a slight upward vertical gradient exists between the unconsolidated zone and the underlying bedrock (Figure E-22).

5.18 K-1414 FUEL STORAGE CENTER

The K-1414 Fuel Storage Center is located within the plant, approximately 100 ft north of the K-1414 Garage (Figure 2). Three steel underground storage tanks (USTs) have been used to contain automotive fuel at the storage center. One 5,500 gallon capacity UST currently contains unleaded gasoline, the second UST was designed for methanol (12,000 gallon capacity) but is now empty, and the third UST has been removed but previously contained diesel fuel. The UST containing diesel fuel was found to be leaking in February 1987.

Results of a Petrotite test indicated that the diesel tank had been leaking at a rate of approximately two gallons per day for an undetermined period. It was estimated from inventory discrepancies that 500 to 600 gallons of diesel were released. Following removal of the tank, approximately 300 to 400 gallons of fuel were recovered from the tank hole by pumping.

One unconsolidated zone well (UNW-64) and two bedrock wells (BRW-45 and BRW-46) were constructed at K-1414 (Figures A-22 and A-23). In addition to these wells, five temporary unconsolidated zone wells (TS-1 through TS-5) and six temporary bedrock wells (TMW-1 through TMW-6) were also constructed. Lithologic logs from the borings indicate that the overburden consists of silty, dark brown clay. Bedrock consists of fractured limestone.

A strong fuel-like odor was noted as BRW-45 was being drilled. Samples collected from this well during development and subsequent sampling events showed free product to be floating on top of the water.

Slug test data from BRW-46 indicate the bedrock has a permeability of approximately 10^{-5} cm/sec. Temporary bedrock wells TMW-1 and TMW-5 were screened in very low water yielding zones and typically did not fully recover between ground-water sampling events. Hence, water-level data from these two wells have been omitted from the potentiometric surface map presented in Figure A-23. Lateral ground-water flow is inferred to be generally to the south and southwest. Available ground-water data indicate the elevation of the potentiometric surface within the shallow bedrock corresponds to the water table surface in the unconsolidated zone at this site (Figures E-23 and E-24). A more complete description of the hydrogeology at this site is included in the preliminary site assessment report prepared by Geraghty & Miller (1987) and in the environmental assessment report and remedial action plan prepared by PEER (1989a & b)

5.19 K-1004-N COOLING TOWER BASIN

The K-1004-N Cooling Tower Basin is located 65 ft south of the K-1004-L Building in the southeast part of the plant (Figure 2). This facility is a 21 x 21 x 3 ft above ground, flow-through, RCW storage tank. The RCW received a chromate, zinc, and phosphate treatment.

One shallow unconsolidated zone well, UNW-59, was completed at a depth of 16 ft in the brown, silty clay at this site. To date this well and other unconsolidated zone wells in this area have generally been dry (Figures A-20 and A-21). During Phase II Extension of the ORGDP Ground-Water Protection Program, one bedrock zone well, BRW-53, was constructed at the site, southwest of the basin. During the development of this well, free-phase hydrocarbon product was noted on the water. Subsequent analyses indicated the presence of PCBs in the product. In an effort to delineate the horizontal extent of ground-water contamination, additional bedrock zone wells (BRW-71 through BRW-73) were installed at the site (Figure A-21).

The inferred direction of shallow ground-water flow in the bedrock in this area of the ORGDP is to the southwest towards the K-1007-B Pond. The fact that all the shallow wells completed in the unconsolidated material in the K-1004 area are dry indicates that at least during part of the year, the water table lies within the bedrock in this area. Hydrographs for wells at the various K-1004 facilities are shown in Figure E-25.

5.20 K-27 AND K-29 RCW LINES

The K-27 and K-29 RCW lines are steel underground pipes located along the south side of the K-27 and K-29 buildings that connect these buildings to the K-832 Cooling Tower Basin (Figure 2). The approximate 2,900 lineal feet of pipes are buried 3 to 10 ft below the surface and range from 16 to 54 inches in diameter. The lines were in use from the early 1950's until 1985 and were used to transport chromate, zinc, and phosphate-treated RCW between the K-832-H Cooling Tower Basin and the K-27/K-29 Process Buildings.

Seven unconsolidated zone wells (UNW-36 through UNW-38, UNW-86 through UNW-88, and UNW-96) have been completed in the vicinity of these pipes in order to determine the hydraulic gradient between the K-27 and K-29 buildings and Poplar Creek (Figure A-16). The overburden consists of brown, silty clay with limestone fragments and ranged from 24 to 31 ft in thickness. In addition to these wells, a bedrock zone well (BRW-69) was constructed adjacent to well UNW-37 (Figure A-17), to provide vertical hydraulic gradient data for the site and ground-water quality data for the bedrock aquifer at the location.

Slug tests were conducted on UNW-37 and UNW-38. Results from these tests indicate permeability ranges from 10^{-3} to 10^{-2} cm/sec in the overburden at this site. Lateral ground-water flow is presumably from northeast to southwest towards Poplar Creek; however, the water level data collected to date indicate the existence of local variations to the regional flow (Figure A-16 and A-17). These variations likely result from the influence of man-made subsurface features at this site. The presence of a large sump and drain lines within 50 ft of well UNW-38 may explain the higher ground-water levels at this location in comparison to the topographically higher UNW-37 and UNW-36 locations. Preliminary ground-water level data from well cluster BRW-69/UNW-37 indicate that the elevation of the potentiometric surface within the shallow bedrock corresponds to the water table surface in the unconsolidated zone (Figure E-26).

The large areas covered by the K-27 and K-29 Buildings along with the extensive pavement serve to divert precipitation elsewhere that would otherwise be recharging the local ground-water system. The existence of storm drains and sumps in the vicinity of UNW-38 may provide recharge to the ground-water system in this area.

5.21 K-31 RCW LINES

The K-31 RCW Lines are steel underground pipes that encircle the K-31 building and connect it with the K-862-E CTB (Figure 2). About 10,000 lineal ft of pipes are buried 3 to 7 ft below grade and range from 24 to 48 inches in diameter. The RCW received a chromate, zinc, phosphate treatment.

Three well clusters (UNW-39/BRW-37, UNW-82/BRW-64, and UNW-81/BRW-65) were constructed at this site. The overburden consists of silty, brown clay with fragments of weathered chert and limestone; the bedrock is composed primarily of limestone with some interbedded shale.

Permeability for the bedrock is on the order of 10^{-4} cm/sec. Available ground-water level data from wells BRW-27/UNW-39 indicate that a downward vertical hydraulic gradient exists between the unconsolidated zone and the underlying bedrock on the west side of this location (Figure E-27). Preliminary ground-water level data from wells BRW-66/UNW-80 indicate that little to no vertical gradient exists on the south side of this site. Lateral ground-water flow is inferred to be to the south towards Poplar Creek and to the west towards the Clinch River (Figures A-18 and A-19).

Available construction information on the RCW lines at the K-31 indicates segments of the lines near the northwest corner lie at approximately the same elevation as the water table in this area. The lines in most of the K-31 area, however, lie from 2 to 15 ft above the water table.

5.22 K-33 RCW LINES

The K-33 RCW Lines are steel, underground pipes that encircle the K-33 Building and connect it to the K-892-G/H and K-892-J Cooling Tower Basins in the northwestern area of the ORGDP (Figure 2). Approximately 12,500 lineal ft of pipes are buried from 3 to 8 ft below grade and range from 12 to 60 inches in diameter. The RCW received a chromate, zinc, and phosphate treatment.

Two well clusters, UNW-40/BRW-28 and UNW-79/BRW-67, were constructed at this site. In addition to these wells, a bedrock zone well, BRW-62, was installed northeast of the K-33 Building. The unconsolidated material ranges in thickness from 5 to 26 ft and consisted of silty, brown clay with fragments of weathered chert. The contact between the Knox and Chickamauga Groups bisects the K-33 Building as indicated by the presence of dolostone in wells BRW-28 and BRW-69, and limestone in BRW-62 (Figure 6).

Initial ground-water level data indicated that a downward vertical hydraulic gradient existed between the unconsolidated zone and the underlying bedrock (Figure E-28); however, more recent data indicate that this gradient is not consistent and may reverse at times. Lateral flow across the site is from north to south (Figures A-18 and A-19). Available construction information for the RCW lines indicates the lines lie from 8 to 18 ft above the water table at most locations; however, elevations for the lines and water table near the southwest corner of the K-33 Building closely correspond.

5.23 K-1004-L RCW LINES

The K-1004-L RCW Lines are underground steel pipes connecting the K-1004-N cooling tower basin to the K-1004-L Building. The approximate 550 lineal ft of pipes are buried from 2 to 5 ft below grade and range from 4 to 12 inches in diameter. The RCW received a chromate, zinc, and phosphate treatment.

One shallow monitor well, UNW-58, was installed in the silty, brown clay at this site (Figures A-20 and A-21). The top of bedrock was encountered at a depth of 16 ft. To date this well has been dry. One bedrock zone monitor well, BRW-54, was installed southwest of the lines near Avenue D. Bedrock consists of limestone. The inferred direction of lateral ground-water flow in the shallow bedrock is to the southwest. The water table lies within the bedrock during some periods at this site as indicated by the dry unconsolidated zone wells installed in the K-1004 area.

5.24 K-720 FLY ASH PILE

The K-720 Fly Ash Pile covers 10 to 15 acres south of the powerhouse and K-770 on the east bank of the Clinch River, southwest of the ORGDP. Fly ash generated by the coal-powered steam plant during the 1940's and 50's was stored at this facility.

Four shallow unconsolidated zone monitor wells (UNW-57, and UNW-73 through UNW-75) were installed at the site (Figure A-24). The unconsolidated material underlying the site consists of silty clay, silty and clayey sand, and gravel, ranging from 20.5 ft to 36 ft thick.

The water table configuration at this site is relatively flat because of the level topography and close proximity of the Clinch River. Permeability, as determined by a slug test conducted in UNW-57, is on the order of 10^{-5} cm/sec. Lateral ground-water flow is to the west, towards the Clinch River. Hydrographs for wells at this site are shown in Figure E-29.

5.25 K-1410 NEUTRALIZATION PIT

The K-1410 Neutralization Pit is a 21 x 14 x 7 ft, 15,800 gallon capacity tank located on the eastern bank of Poplar Creek, 600 ft west of the K-25 Building (Figure 2). Chemical compounds used at the facility include nickel sulfate, degreasing compounds, acid and other corrosive solutions. Operation of the unit began in 1975 and was discontinued in 1979.

One shallow monitor well,UNW-60, was constructed in the silty, brown clay at this site (Figure A-16). One bedrock zone well, BRW-58, was installed adjacent to UNW-60 (Figure A-17). Bedrock consists of micritic limestone. Lateral ground-water flow is inferred to be to the west towards Poplar Creek. Preliminary ground-water level data indicate that a downward vertical gradient exists between the water table surface in the unconsolidated zone and the potentiometric surface in the bedrock (Figure E-30).

5.26 K-901-A HOLDING POND

K-901-A Holding Pond is a surface impoundment of approximately five acres located 1,600 ft west of the K-31 Building adjacent to Clinch River, at the western edge of the ORGDP (Figure 2). The pond, which was built in the early 1970's, contains sludge composed of chromium-hydroxide precipitates. The sludge also contains lead, nickel, copper, and uranium.

The pond was used for settling chromium-hydroxide (trivalent chromium) precipitates generated by the electro-chemical treatment (ANDCO) of chromated RCW blowdown from the K-25 RCW system. The water soluble hexavalent chromium was reduced to the insoluble trivalent chromium at the ANDCO unit and the resulting precipitate was allowed to settle in the pond.

Four unconsolidated zone and bedrock well clusters (UNW-46/BRW-33; UNW-66/BRW-35; UNW-65/BRW-34; and UNW-67/BRW-68) and one unconsolidated zone well (UNW-77) were constructed at this site (Figures A-27 and A-28). The pond itself sits astride the contact between the Knox Group and the overlying Chickamauga Group. Well BRW-33 located to the northeast of the pond, was screened in dolostone of the Knox Group. Wells BRW-34, BRW-35, and BRW-68 all located to the south of the pond were screened in the Chickamauga Group. The overburden consists of silty, brown or reddish-orange clay. Extensive solution cavity development was encountered in the dolostone at BRW-33 and in the limestone at BRW-68.

Permeabilities for the unconsolidated zone and bedrock are approximately 10^{-6} cm/sec and 10^{-3} cm/sec, respectively, as determined by slug tests conducted on UNW-46 and BRW-34. Ground-water level data from all four well pairs indicate that the predominate vertical hydraulic gradient is downward between the unconsolidated zone and the underlying bedrock (Figure E-31). Lateral ground-water flow in both the unconsolidated zone and the bedrock is primarily towards the pond from the surrounding areas. Avenues for ground-water flow away from the pond likely occur at the southeastern corner towards Poplar Creek and along the western edge in the vicinity of the discharge to the Clinch River.

5.27 K-1004 AREA LABORATORY DRAIN

The K-1004 Area Laboratory Drain carries laboratory wastes from several laboratories on the southern side of the ORGDP to the K-1007-B Holding Pond approximately 400 yards southwest of the ORGDP (Figure 2). Prior to 1984, approximately 2000 gallons per year of experimental, analytical, and glassware cleaning solutions were disposed of through the drain. The solutions included acids, bases, solvents and various organics. Currently the drain is used for disposal of rinse water and discharges less than 1 percent of the total flow to the K-1007-B Holding Pond.

One well cluster consisting of an unconsolidated zone and a bedrock well (UNW-47/BRW-36), one unconsolidated zone well (UNW-49), and three bedrock wells (BRW-42, BRW-55, and BRW-56), were constructed to characterize the hydrogeology in the area of the drain (Figures A-20 and A-21). Lithologic logs indicate the overburden is composed of brown, silty clay which ranged in thickness from 10 to 27 ft and the bedrock consists primarily of limestone with some interbedded shale.

The permeability for both the unconsolidated zone and bedrock is approximately 10^{-5} cm/sec, as determined by slug tests conducted in UNW-47 and BRW-36. Lateral flow across the site is to the southwest, towards the K-1007-B Holding Pond and Poplar Creek. Ground-water level data indicate an upward vertical hydraulic gradient exists at times between the bedrock and the unconsolidated zone in the vicinity of the K-1007 Building (Figure E-25). Monitor wells in the K-1004 area have shown that the water table lies entirely within the bedrock during some periods in this area.

5.28 K-1503 NEUTRALIZATION PIT

The K-1503 Neutralization Pit is located just south of the K-1503 Building in the northeast part of the Plant (Figure 2). The in-ground pit is approximately 10 ft square by 12 ft deep. The facility was used for the neutralization of corrosive liquids generated in water-softening operations in the past. Currently, it is used only as a sump for temporary holding of corrosive liquids.

One well cluster, UNW-92/BRW-48, one shallow well, UNW-56, and one bedrock zone well, BRW-70, were installed at this site. The unconsolidated material underlying the site consists of silt, and silty or sandy clay; bedrock consists primarily of shale with some intercalated limestone. Ground-water level data from these wells and from wells located in adjacent sites indicate that generally the lateral flow in both the unconsolidated and bedrock zones underlying the site is to the north-northwest, toward the Mitchell Creek Valley (Figures A-25 and A-26). Locally a more westerly component of ground-water flow may be present. Preliminary ground-water level data from well cluster BRW-48/UNW-92 indicate that an upward vertical gradient exists between the potentiometric surface in the shallow bedrock and the water table surface in the unconsolidated zone (Figure E-32).

5.29 K-1004-L VAULTS

The K-1004-L vaults contain concrete casts for storage of reactor return samples. They are located under the south end of the K-1004-J Building in the southeastern part of the ORGDP (Figure 2) and were used in the 1950's and 60's. A crane system was used to remove the tops of the casts and to place reactor-return samples in them. At the time of the Phase II well installation program the vaults were thought to be under the K-1004-L Building.

One well cluster, UNW-61/BRW-38, and three bedrock wells, BRW-50 through BRW-52, were installed next to the K-1004-L Building (Figures A-20 and A-21). Lithologic logs indicate the unconsolidated material is composed of brown, silty clay with limestone fragments and is underlain by bedrock consisting primarily of limestone with some interbedded shale. The top of bedrock was encountered at depths from 10.5 ft to 21 ft at this location.

The permeability of the bedrock at well BRW-38, as determined by slug test, is on the order of 10^{-4} cm/sec. Except during periods of heavy rainfall the adjacent unconsolidated zone monitor well is dry indicating the occurrence of the water table within the bedrock during the period of record at this site. The inferred direction of shallow ground-water flow in the bedrock in this area is to the southwest. Hydrographs for wells at this site are included on Figure E-25.

5.30 K-1401 ACID LINE

The K-1401 Acid Line is an underground vitreous clay pipeline between the east side of the K-1401 Building and K-1407-A Neutralization Facility in the northeastern part of the ORGDP (Figure 2). Hydrochloric acid, sodium hydroxide, and other chemicals were used in the K-1401 metals cleaning area. Breaks in the line were discovered in the early 1970's through which corrosives were discharged to a storm drain and the surrounding soil. The lines were repaired with a plastic liner and are presently in use.

Two unconsolidated zone wells, UNW-51 and UNW-52, were installed in the brown, silty clay and weathered siltstone at this site. The thickness of the overburden ranged from 18.5 to 33 ft. Ground-water level data from these two wells and from wells located in adjacent sites (Figures A-25 and A-26) indicate that the lateral flow in the unconsolidated zone underlying the site is to the north and northwest, towards the Mitchell Creek Valley. Hydrographs for the wells are shown in Figure E-22. Elevations are not known for the acid line; however, elevations of the RCW lines in this vicinity indicate they are buried approximately 2 to 3 ft above the water table in this area of the plant.

5.31 K-1420 OIL STORAGE AREA

The K-1420 Oil Storage Area consists of a paved area 50 x 275 ft located 75 ft north of the K-1420 Building, along the south bank of Mitchell Creek (Figure 2). Uranium-contaminated oil is stored at the facility in five gallon buckets for transfer to 55 gallon drums, then transported to the waste-oil decontamination facility inside K-1420.

Two well clusters, UNW-62/BRW-39 and UNW-95/BRW-47, and one unconsolidated zone well, UNW-94,were constructed at this site. Lithologic logs indicate that the unconsolidated material consists of silty, brown and red clay which is underlain by bedrock composed of interbedded limestone and shale. The top of bedrock was encountered from 18 to 23 below the ground surface. Available ground-water level data indicate that a downward vertical hydraulic gradient exists between the unconsolidated zone and the underlying bedrock (Figure E-33). Lateral flow across the site is to the west, towards the Mitchell Creek Valley (Figures A-25 and A-26).

5.32 K-1420 PROCESS LINES

The K-1420 Process Lines were underground pipelines which connected the K-1420 Building to the K-1407-B Holding Pond, a few hundred ft west of K-1420 (Figure 2). The pipes were used to transport radioactive liquid from K-1420, where non-hazardous chemicals are used to clean uranium-contaminated equipment, to the K-1407-B Pond. One of the abandoned pipelines was found to contain PCBs, mercury, and uranium. The source of the PCBs is unknown; however, the mercury probably was introduced through the mercury-recovery room at K-1420.

One unconsolidated zone monitor well, UNW-63, was constructed in the brown and gray, silty clay at this site. Auger refusal was encountered at a depth of 20.5 ft. Ground-water level data from this well and from wells located in adjacent sites (Figure A-25) indicate that lateral flow in the unconsolidated zone underlying the site is to the northwest, toward the Mitchell Creek Valley and the K-1407 waste area grouping. A hydrograph for UNW-63 is shown on Figure E-33.

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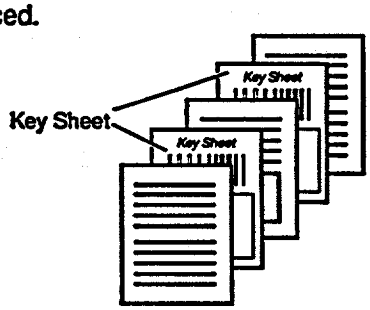

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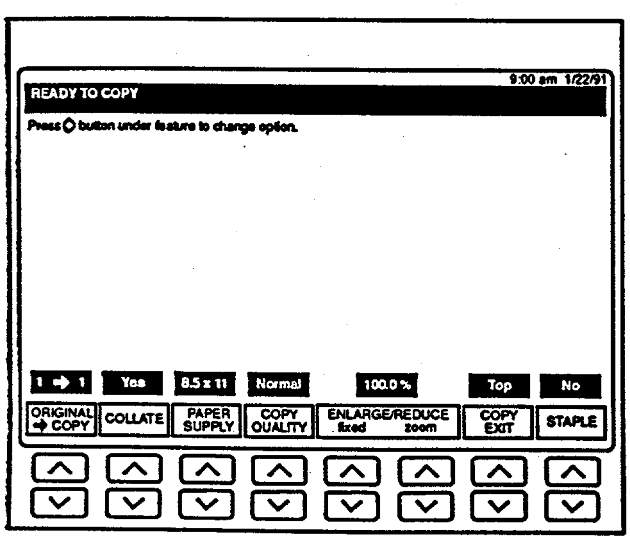

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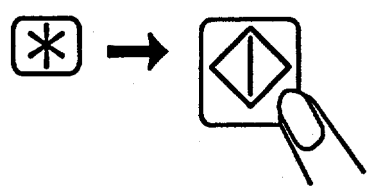

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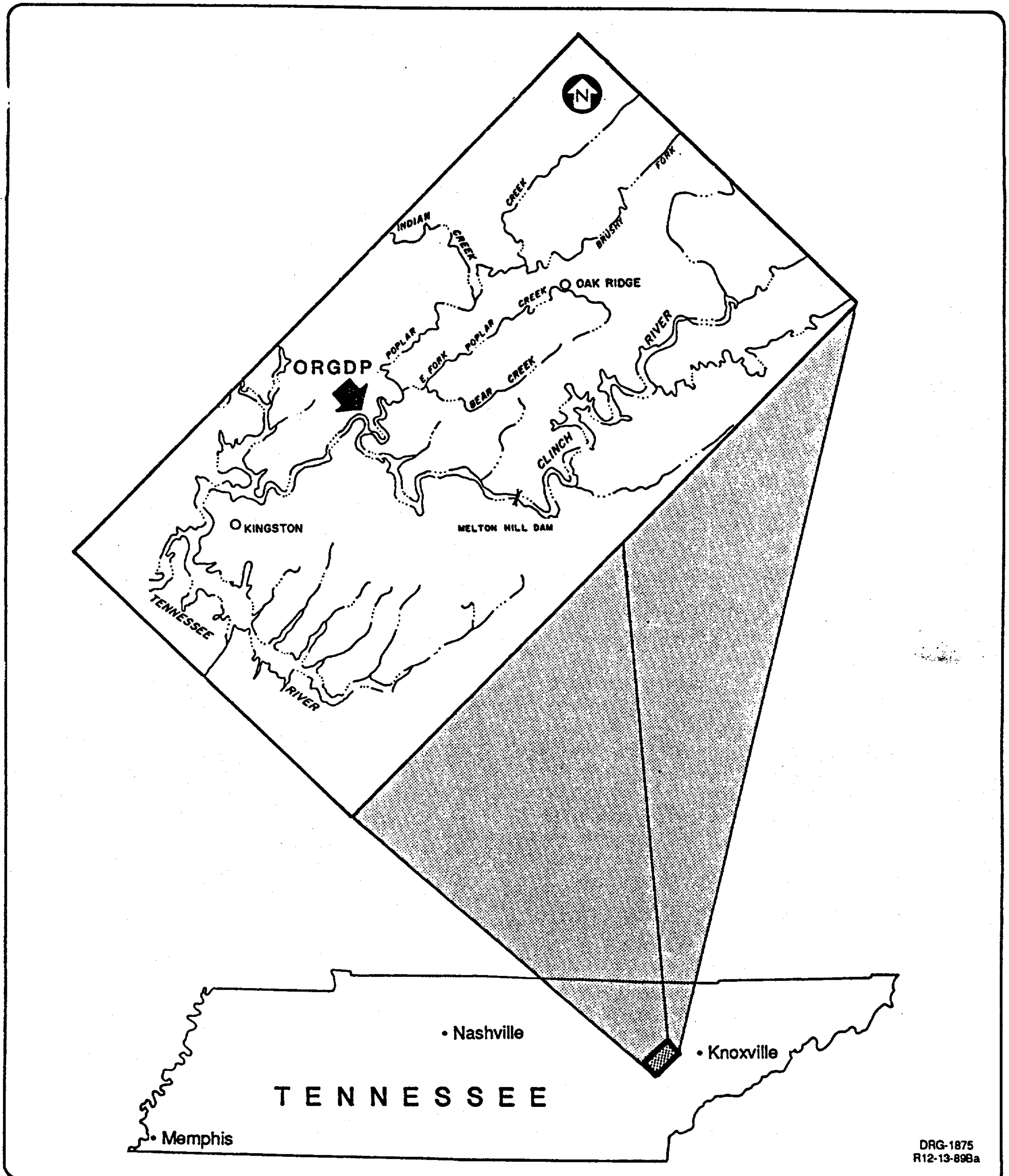

Figure 1. Regional Map of the Oak Ridge Gaseous Diffusion Plant

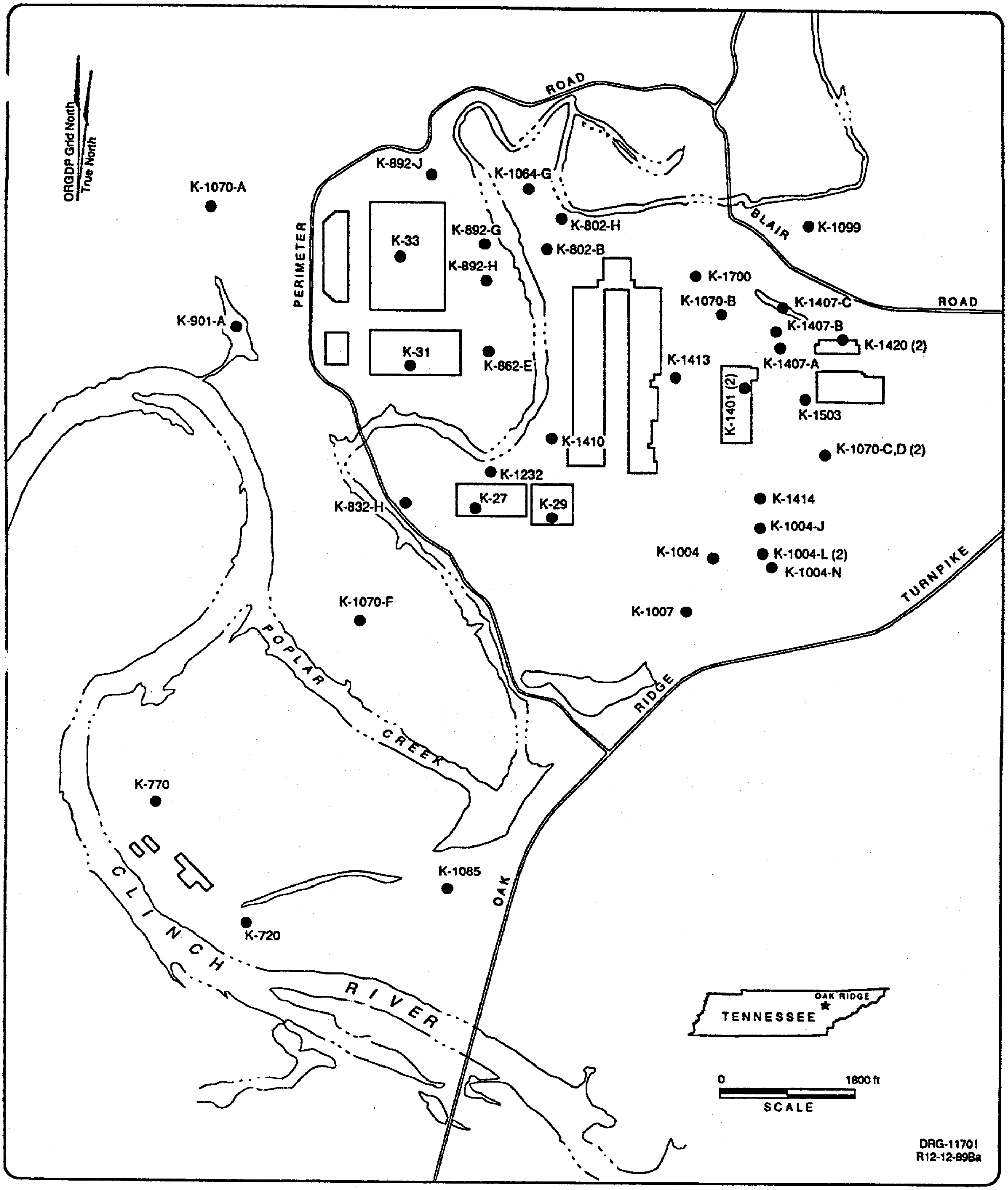

Figure 2. 41 Waste-Management Sites at the ORGDP

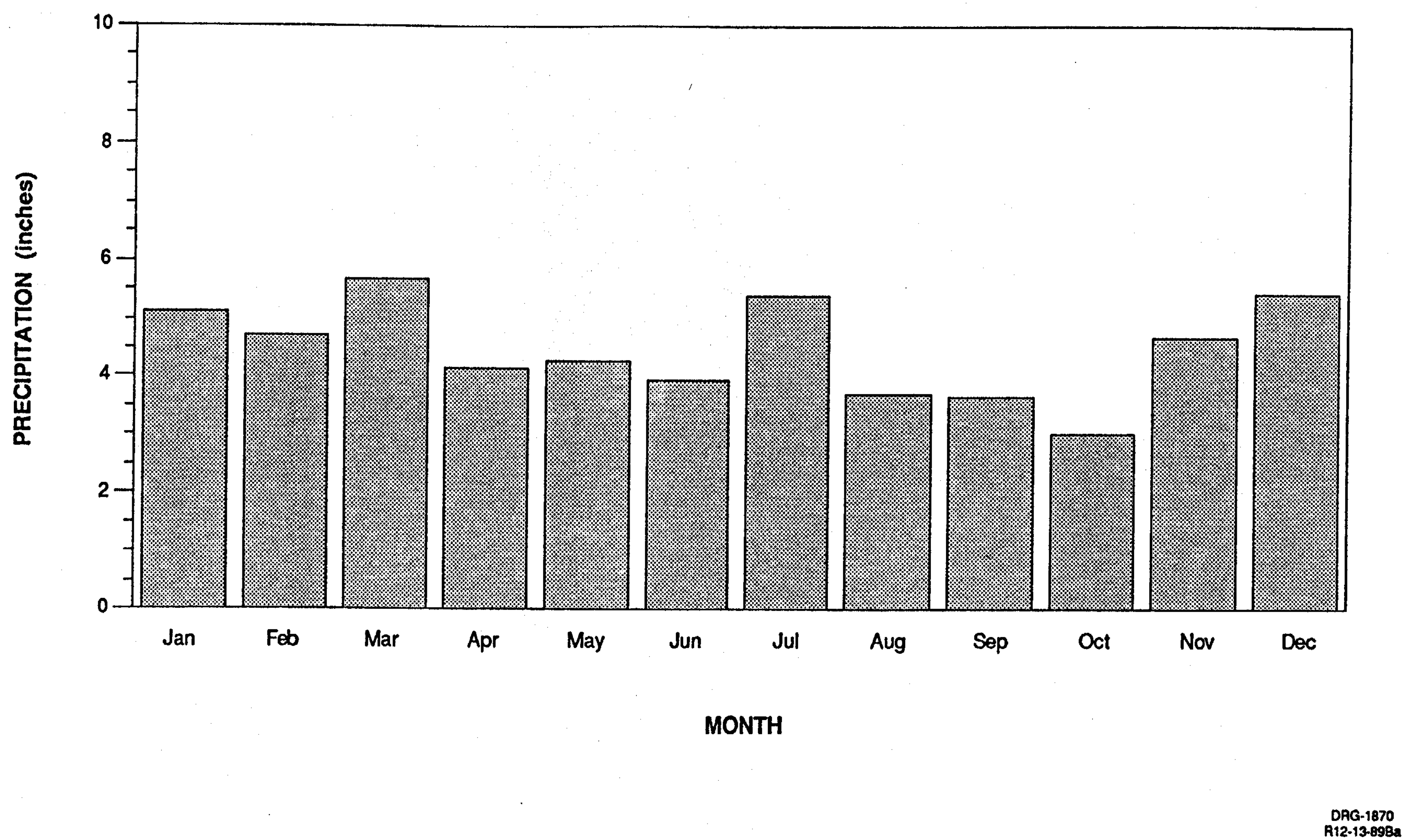

Figure 3. Mean Monthly Precipitation at Oak Ridge, Tennessee, 1959-1988

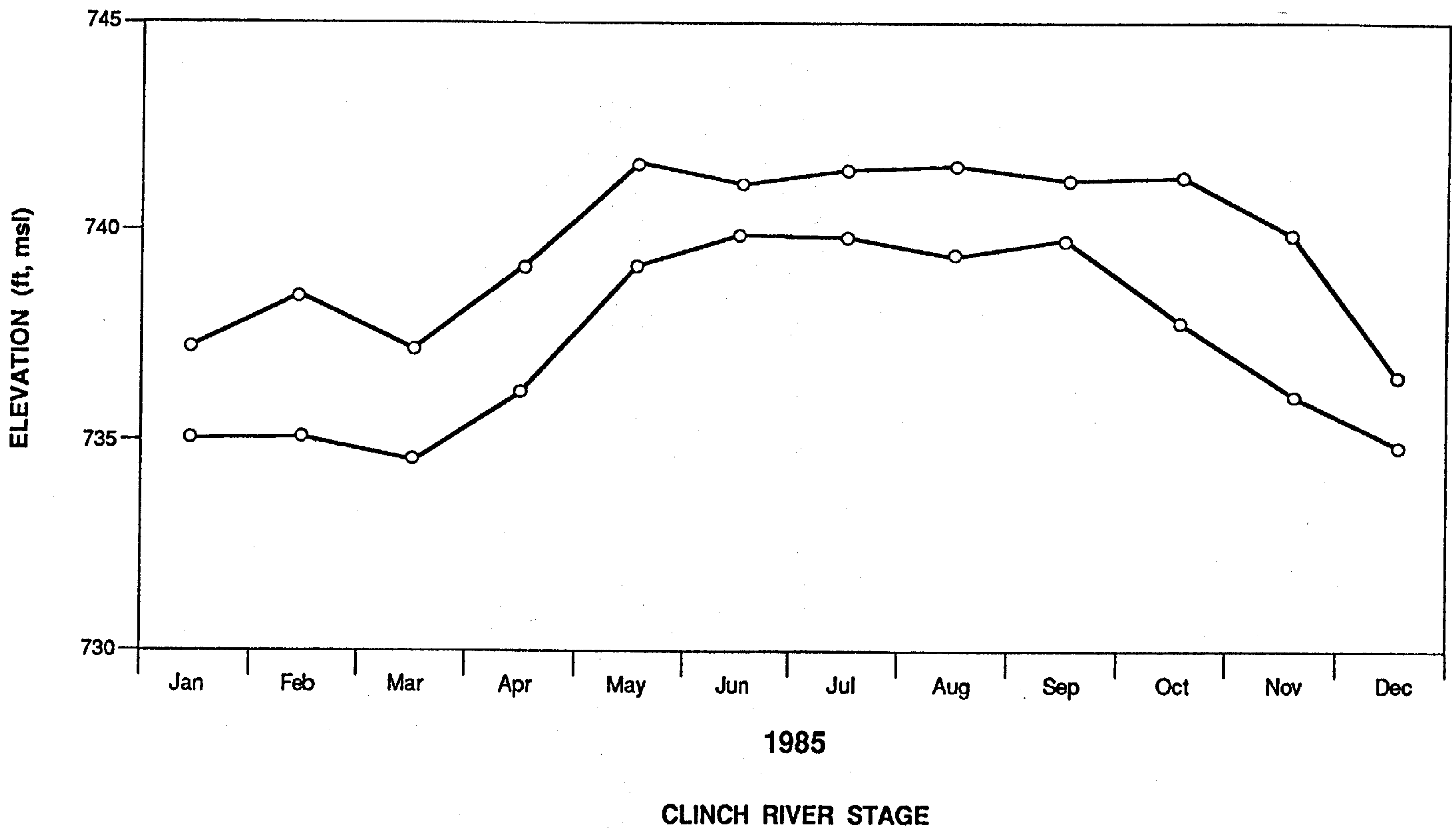

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Figure 4. Monthly Maximum and Minimum Stage, 1985, Clinch River at the ORGDP

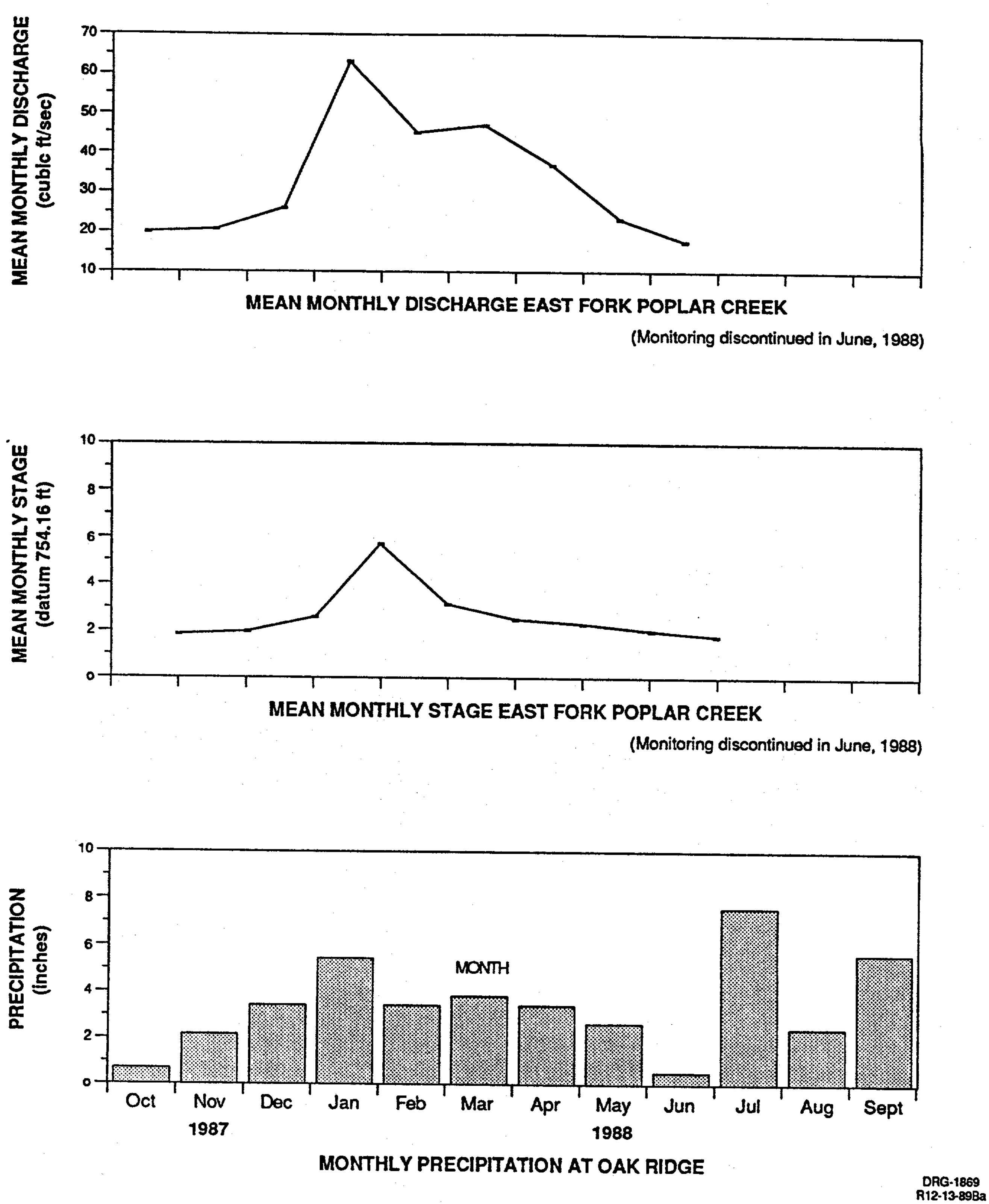

Figure 5. Monthly Precipitation at Oak Ridge, Mean Monthly Discharge and Mean Monthly Stage, East Fork Poplar Creek, 1988 Water Year

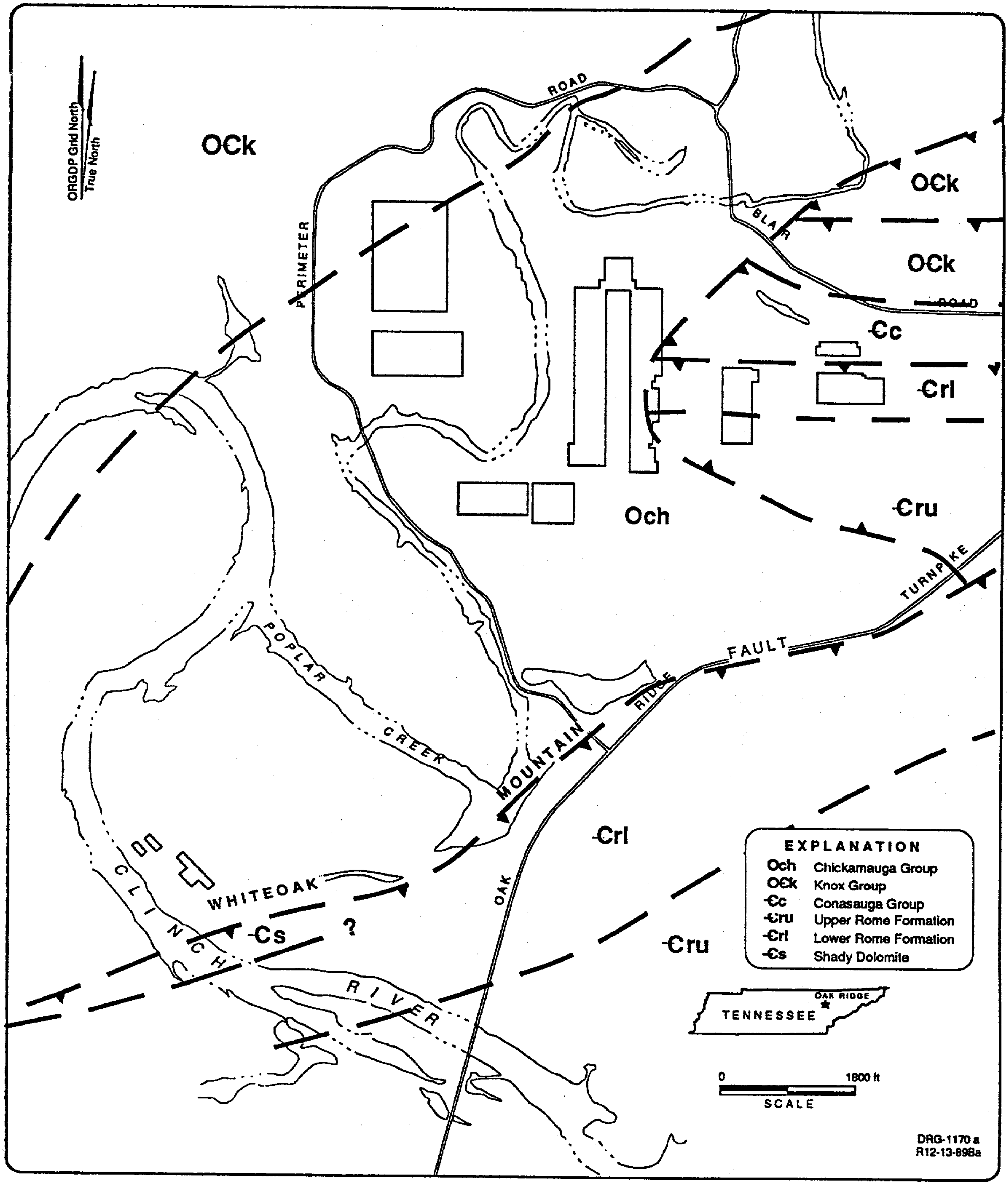

Figure 6. Geology in the Vicinity of the Oak Ridge Gaseous Diffusion Plant

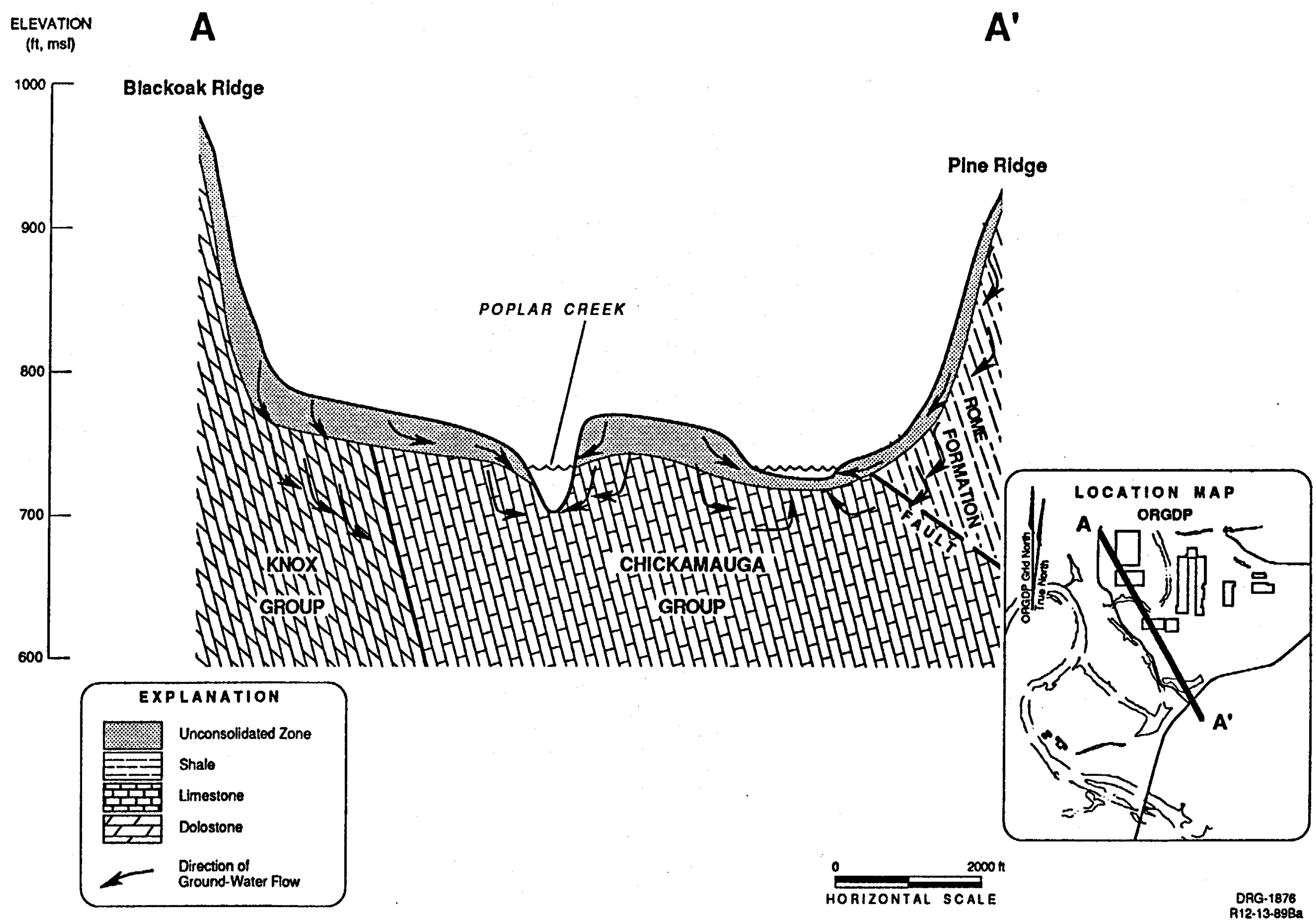

Figure 7. Hydrogeologic Section A-A' with Generalized Ground-Water Flow Paths

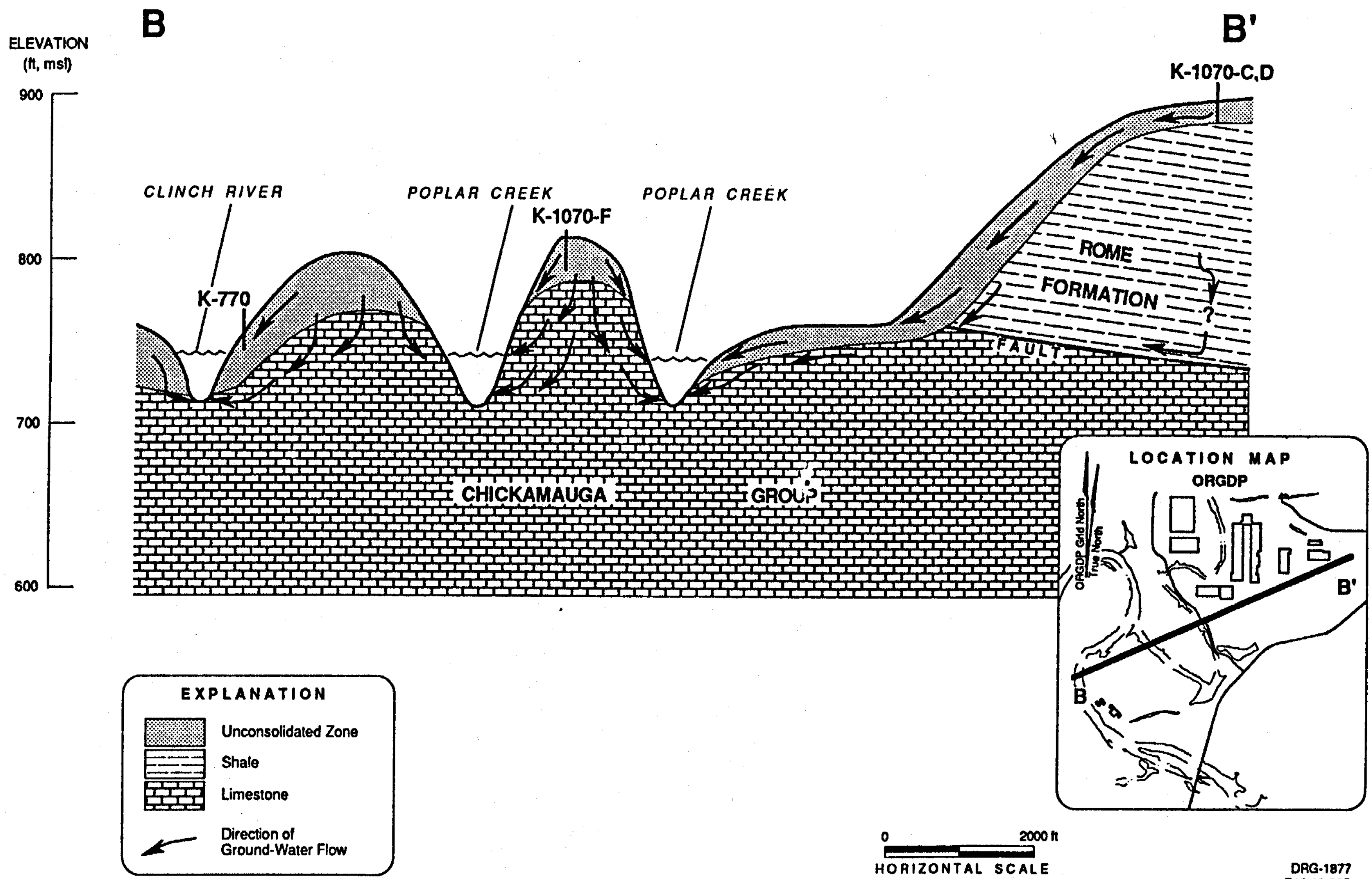

Figure 8. Hydrogeologic Section B-B' with Generalized Ground-Water Flow Paths

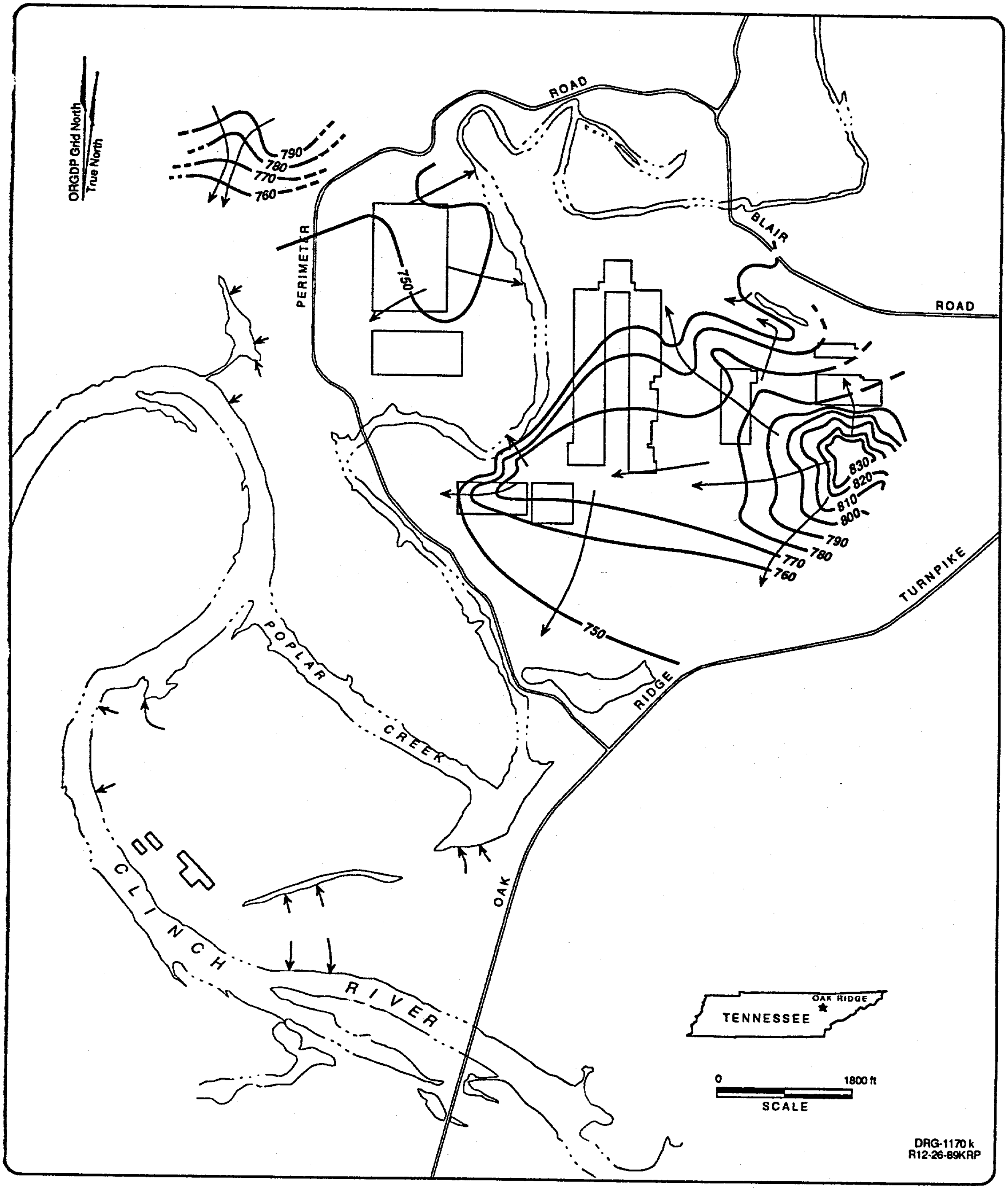

Figure 9. Contours of the Water Table and Inferred Ground-Water Flow Paths in the Unconsolidated Zone, ORGDP Area

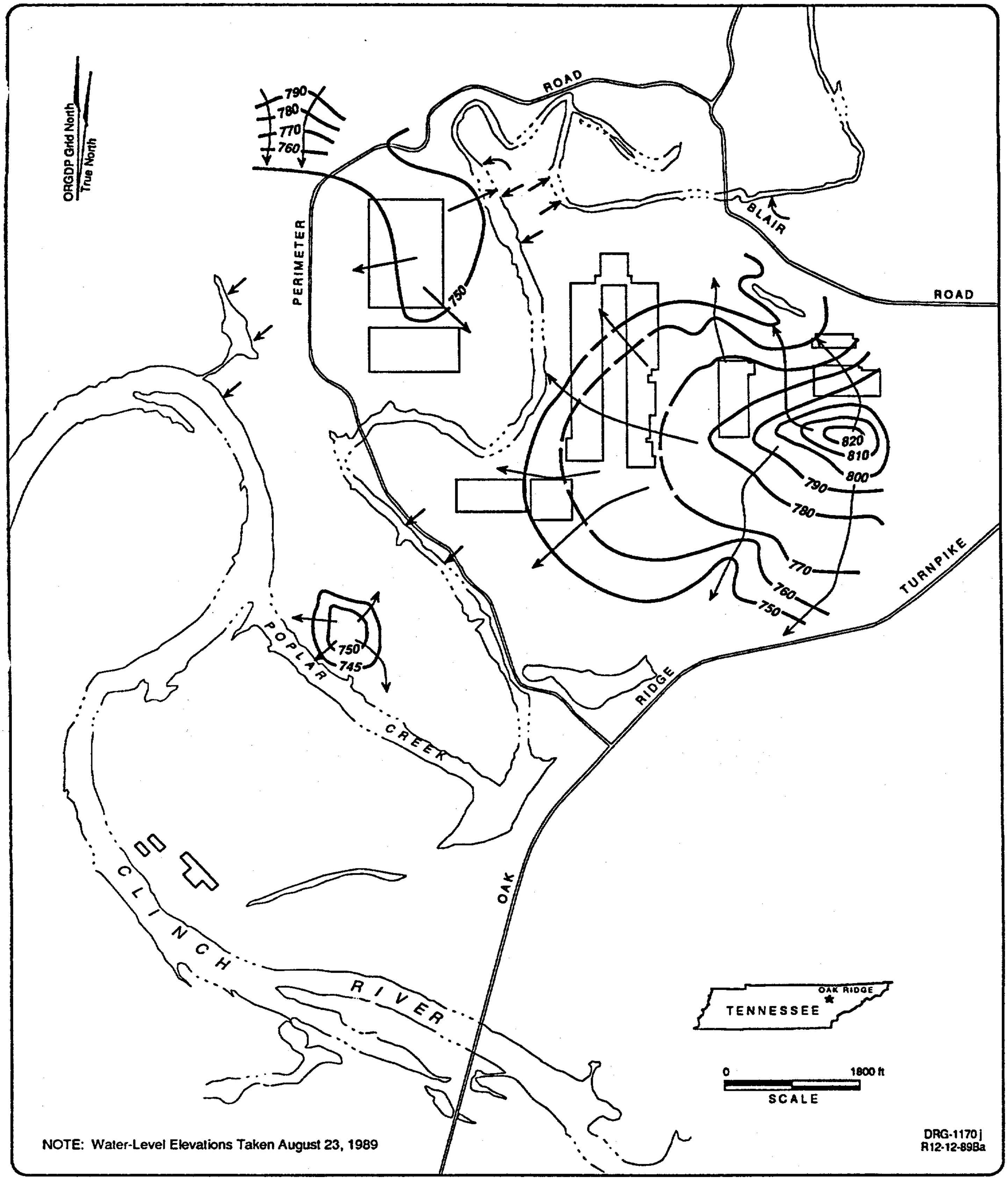

Figure 10. Contours of the Potentiometric Surface and Inferred Ground-Water Flow Paths in the Bedrock, ORGDP Area

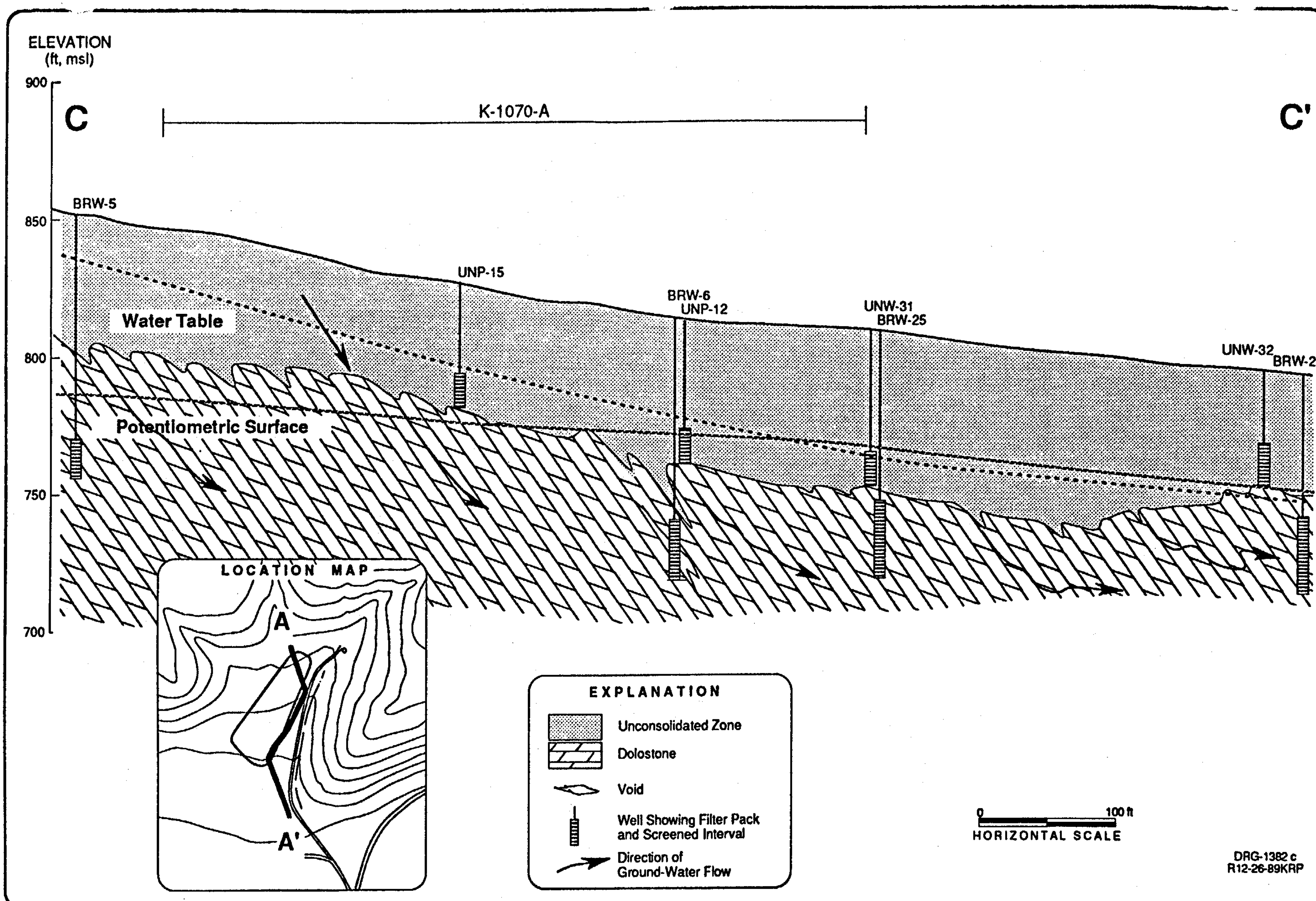

Figure 11. Hydrogeologic Section C-C' through the K-1070-A Site with Generalized Ground-Water Flow Paths, August 23, 1989

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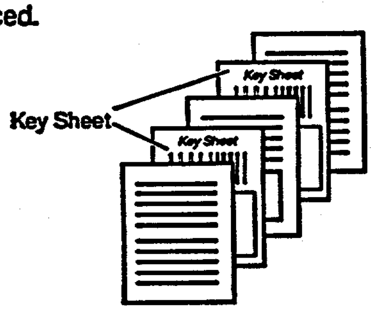

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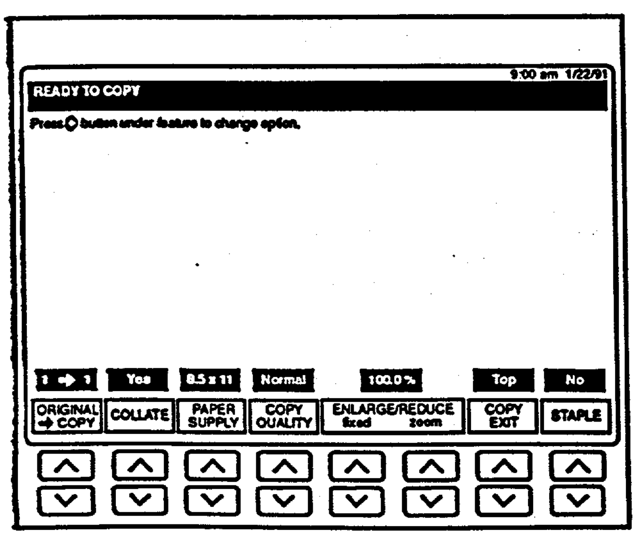

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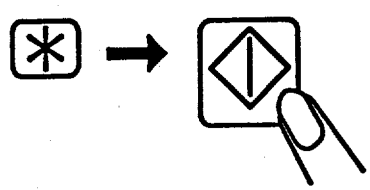

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APPENDIX A

Site Maps and Hydrogeology

APPENDIX A

Page

APPENDIX A
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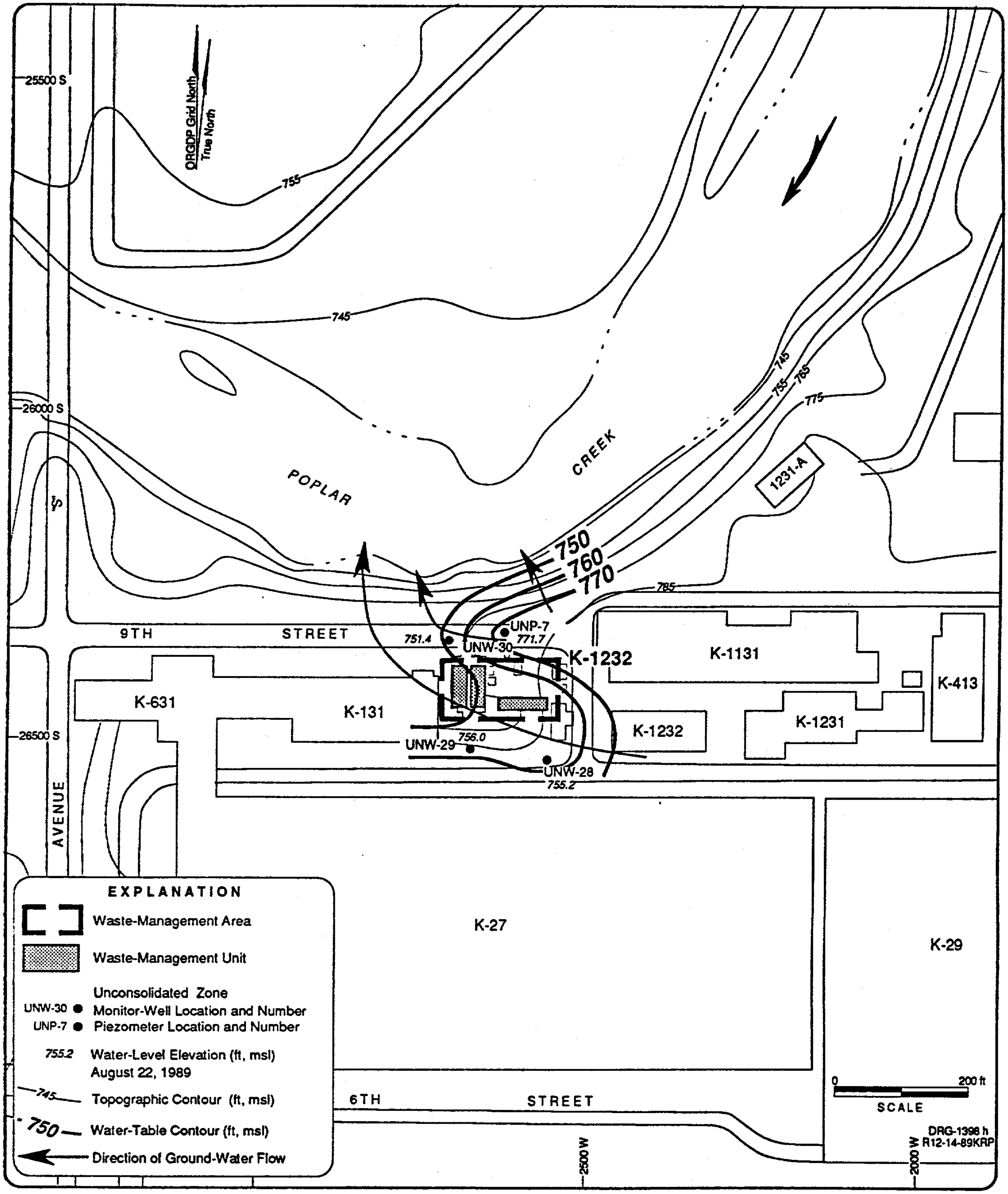


Figure A-1. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1232 Site

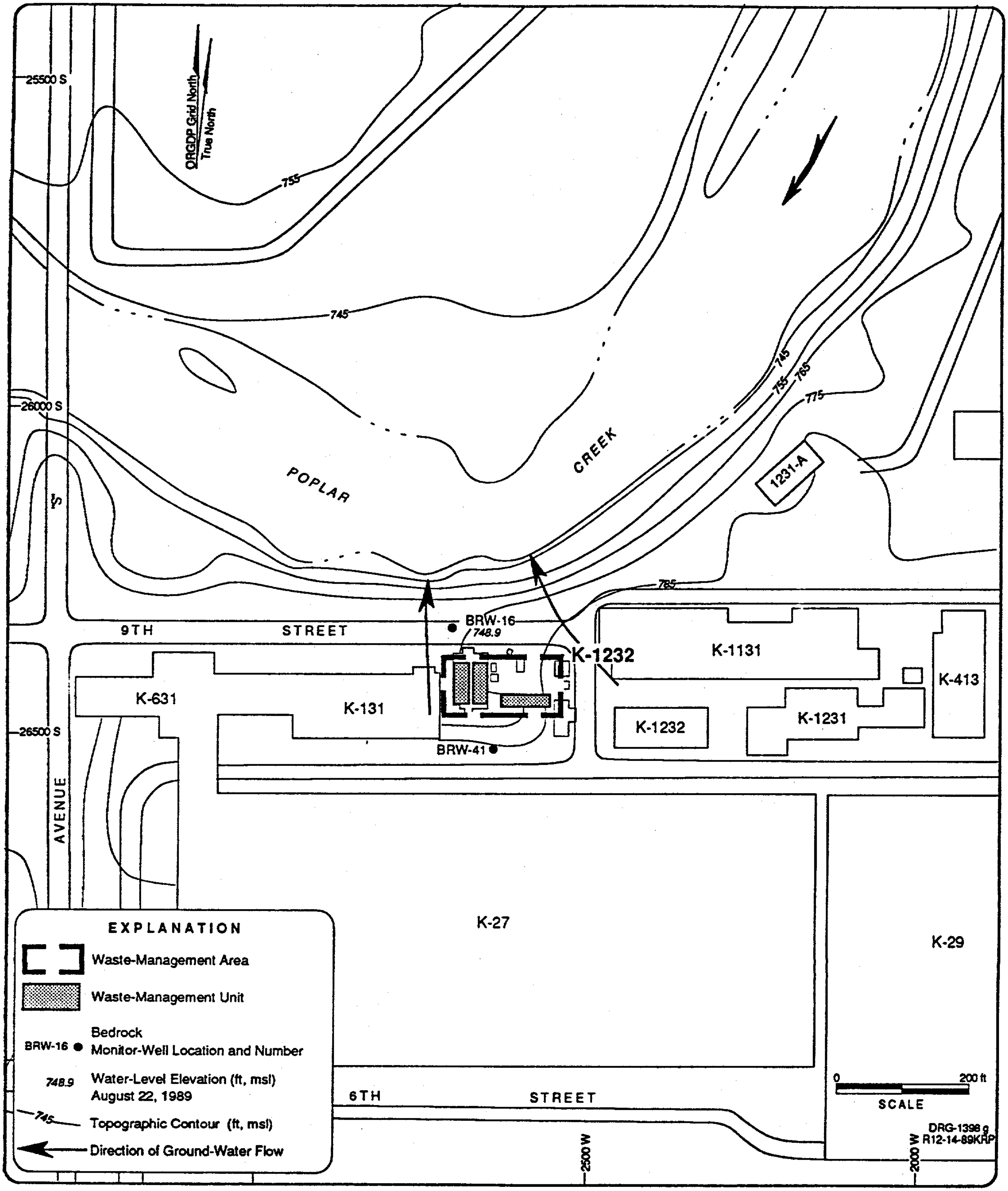


Figure A-2. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1232 Site

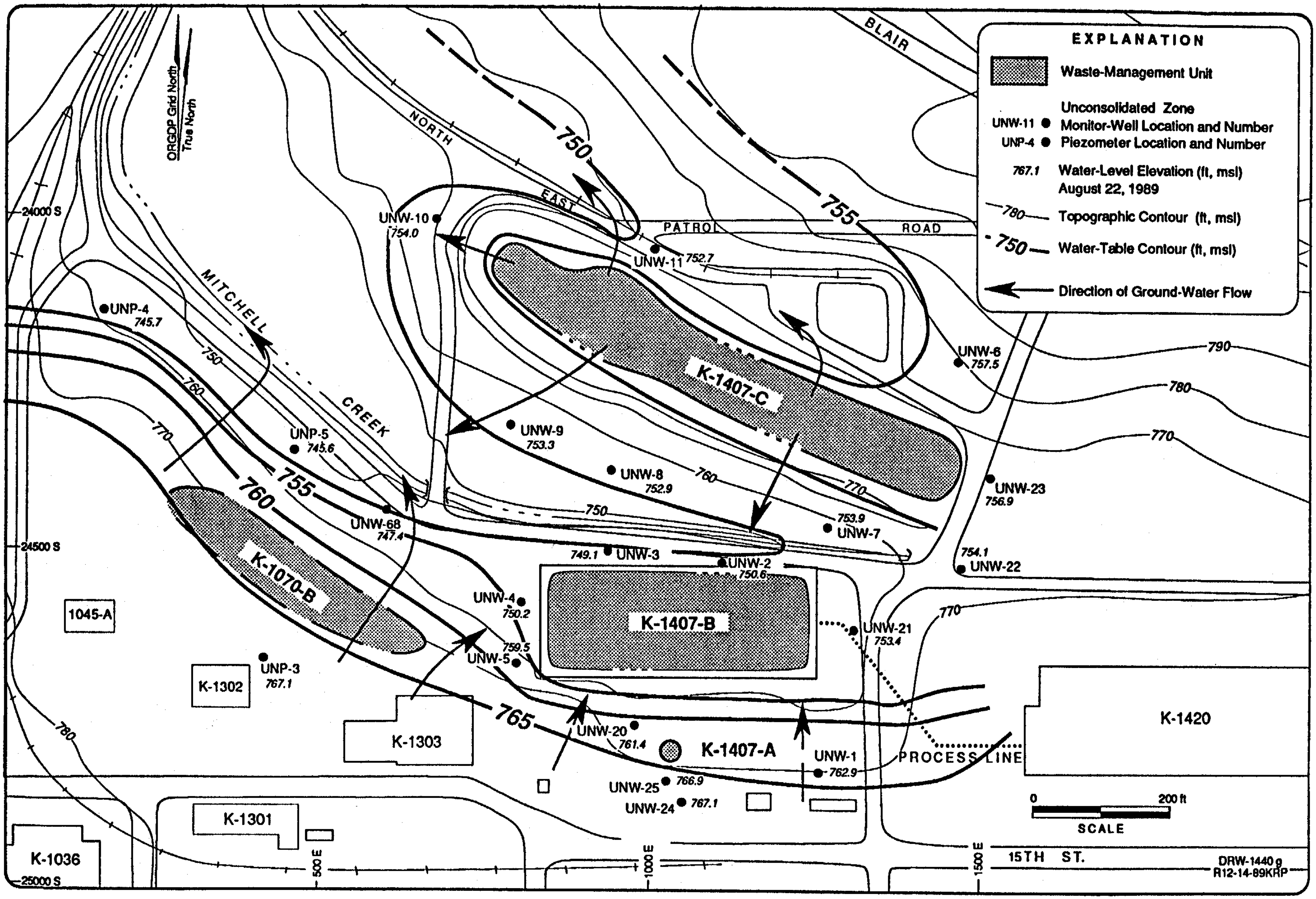


Figure A-3. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1070-B, K-1407-A, K-1407-B, and K-1407-C Sites

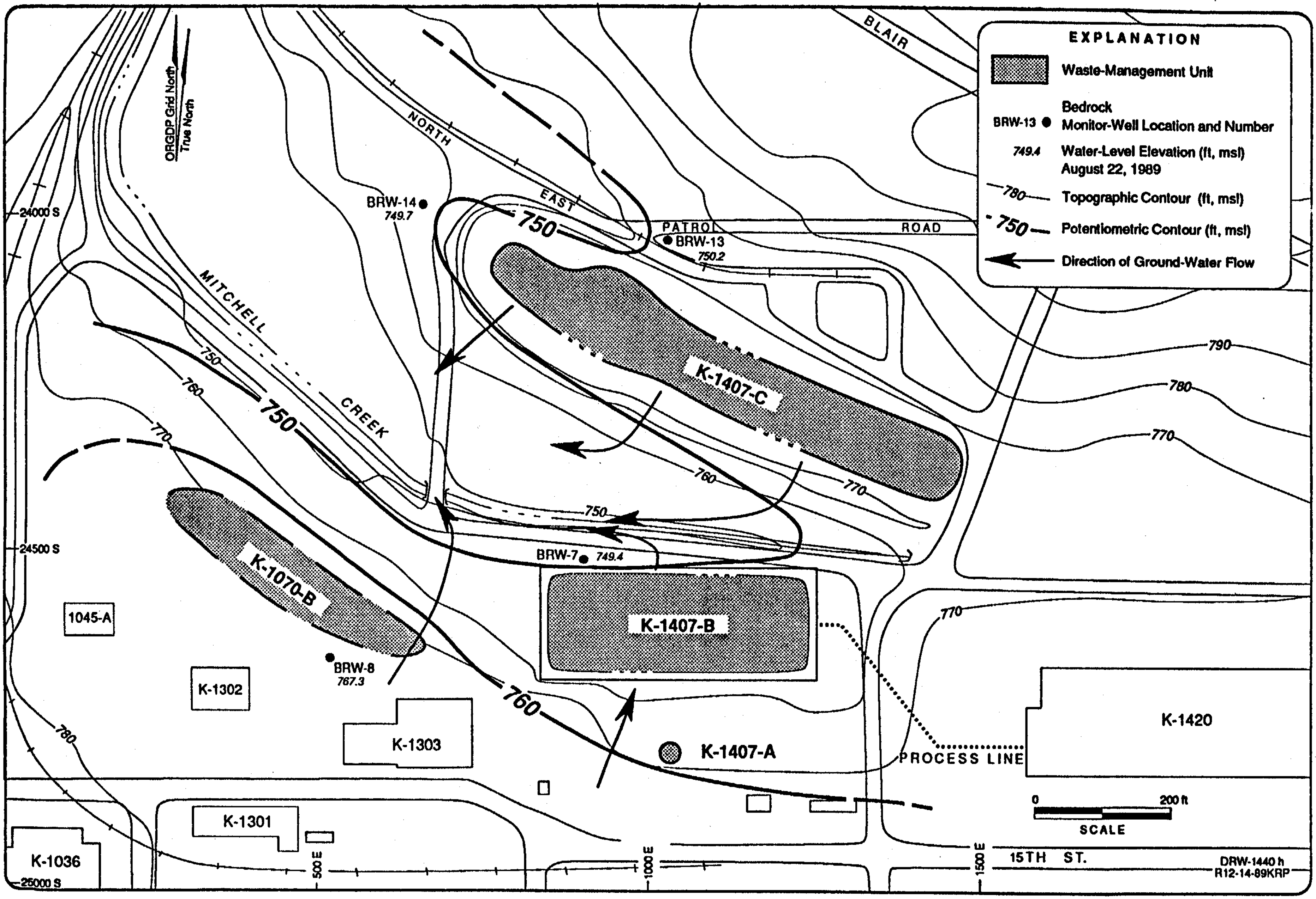


Figure A-4. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1070-B, K-1407-A, K-1407-B, and K-1407-C Sites

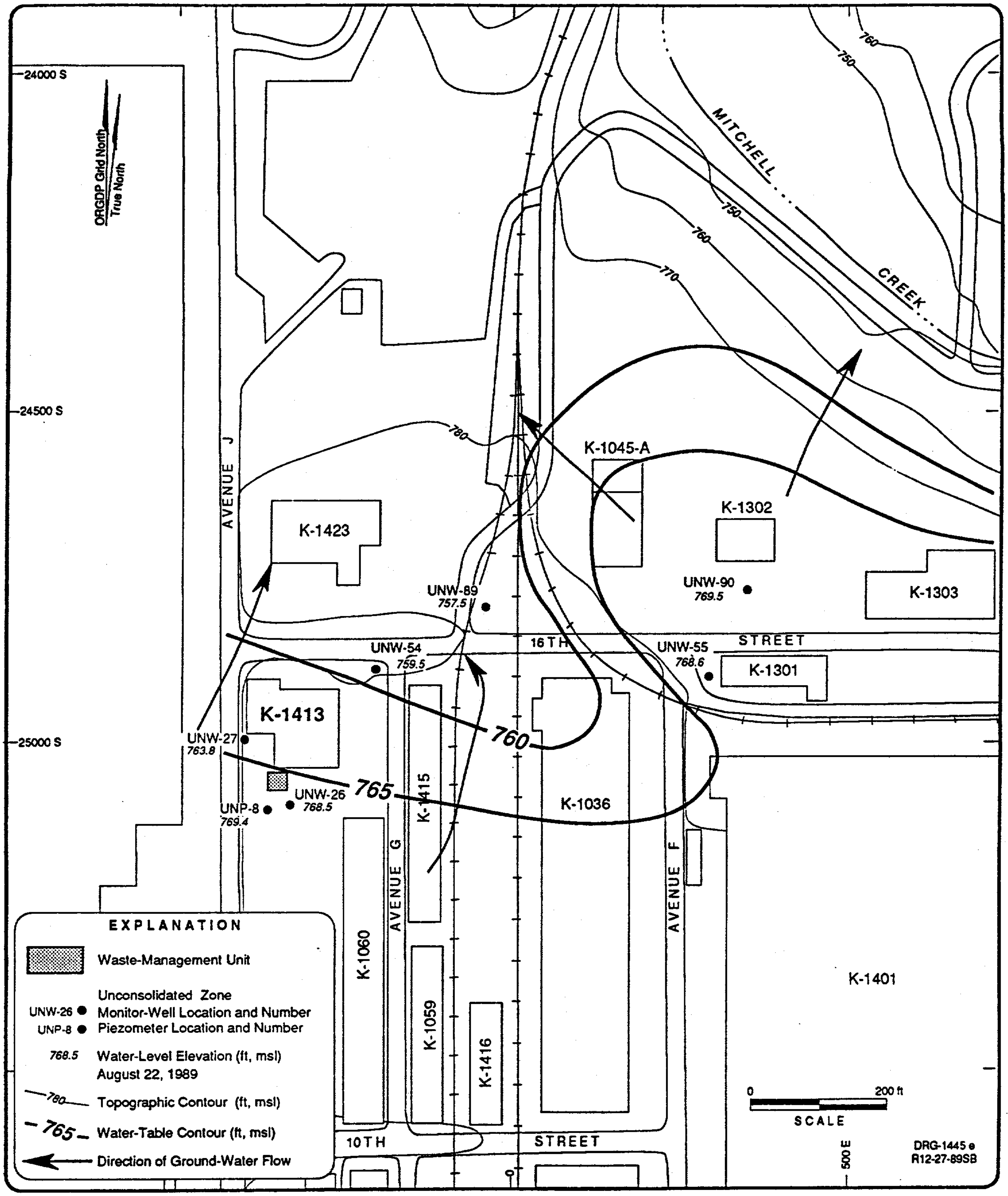


Figure A-5. Monitor-Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1413 Site

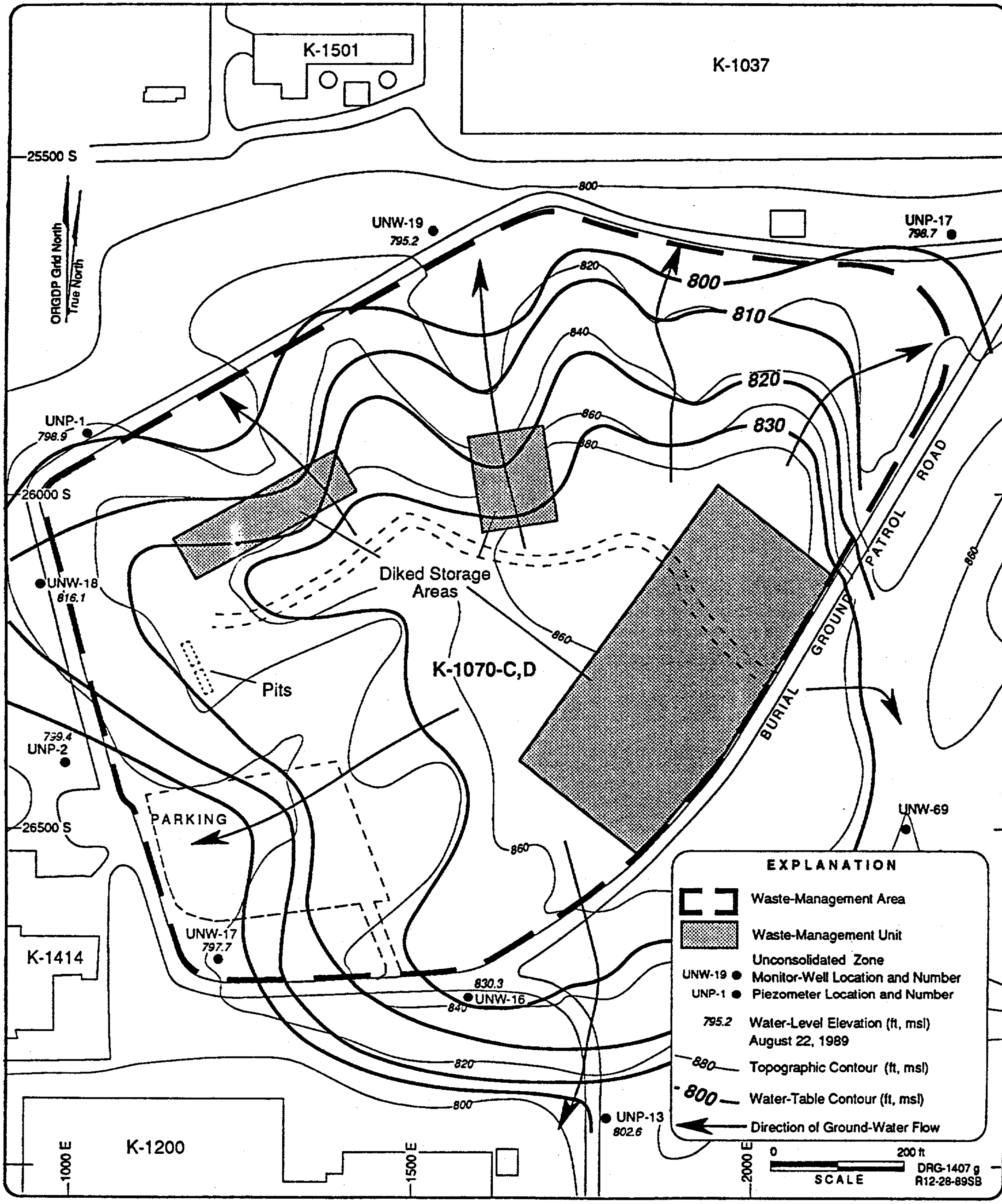


Figure A-6. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1070-C,D Site

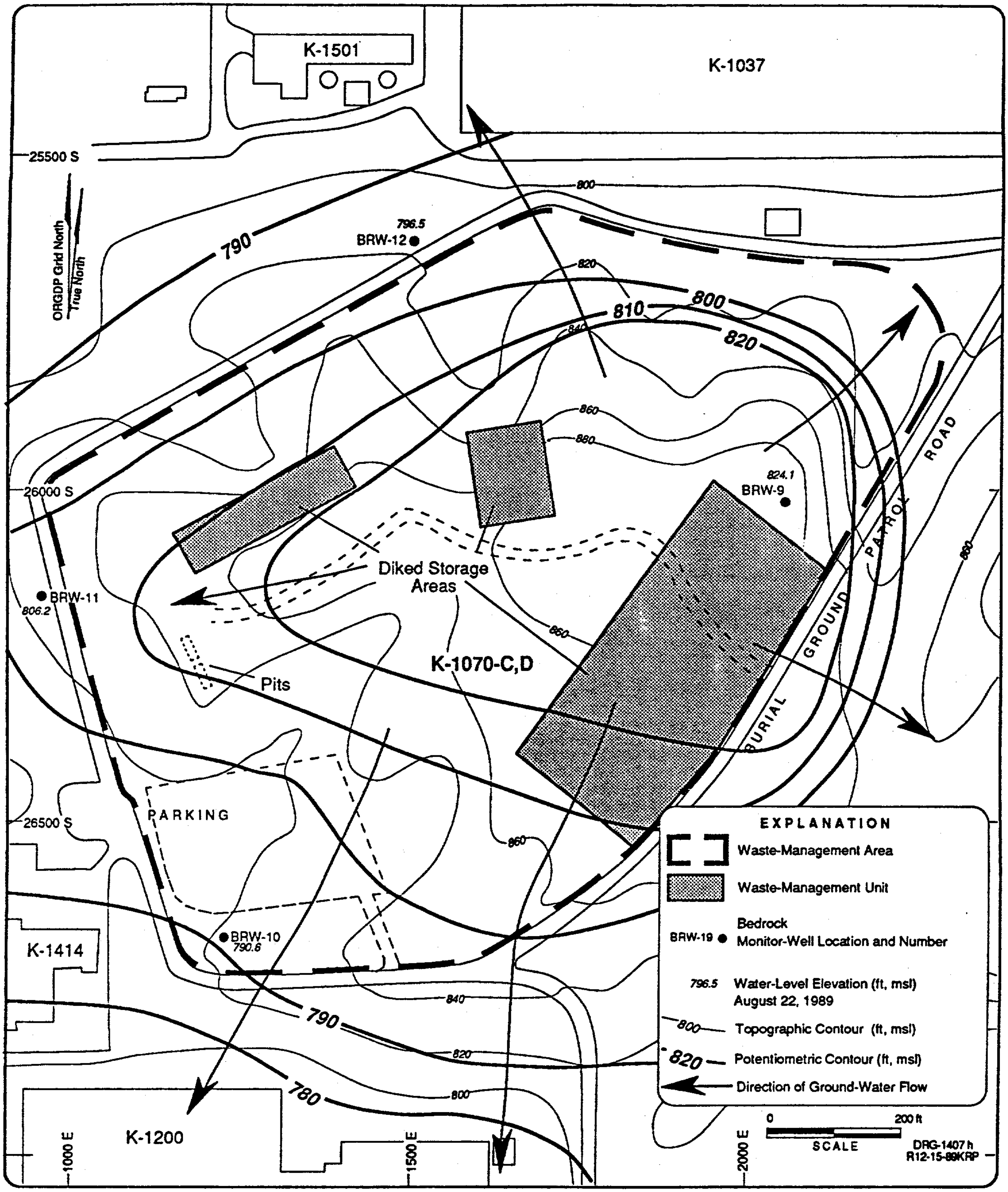


Figure A-7. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1070-C,D Site

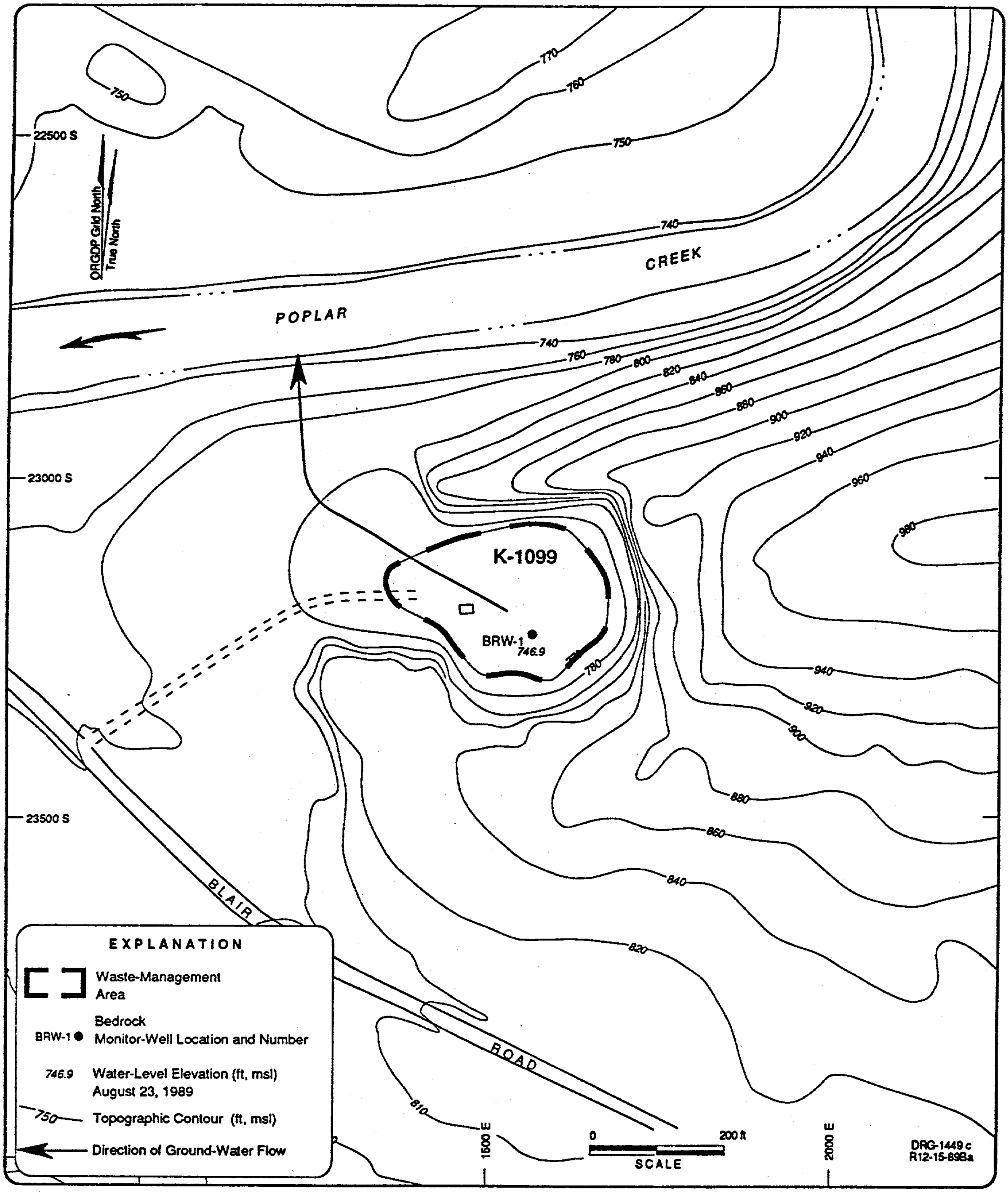


Figure A-8. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1099 Site

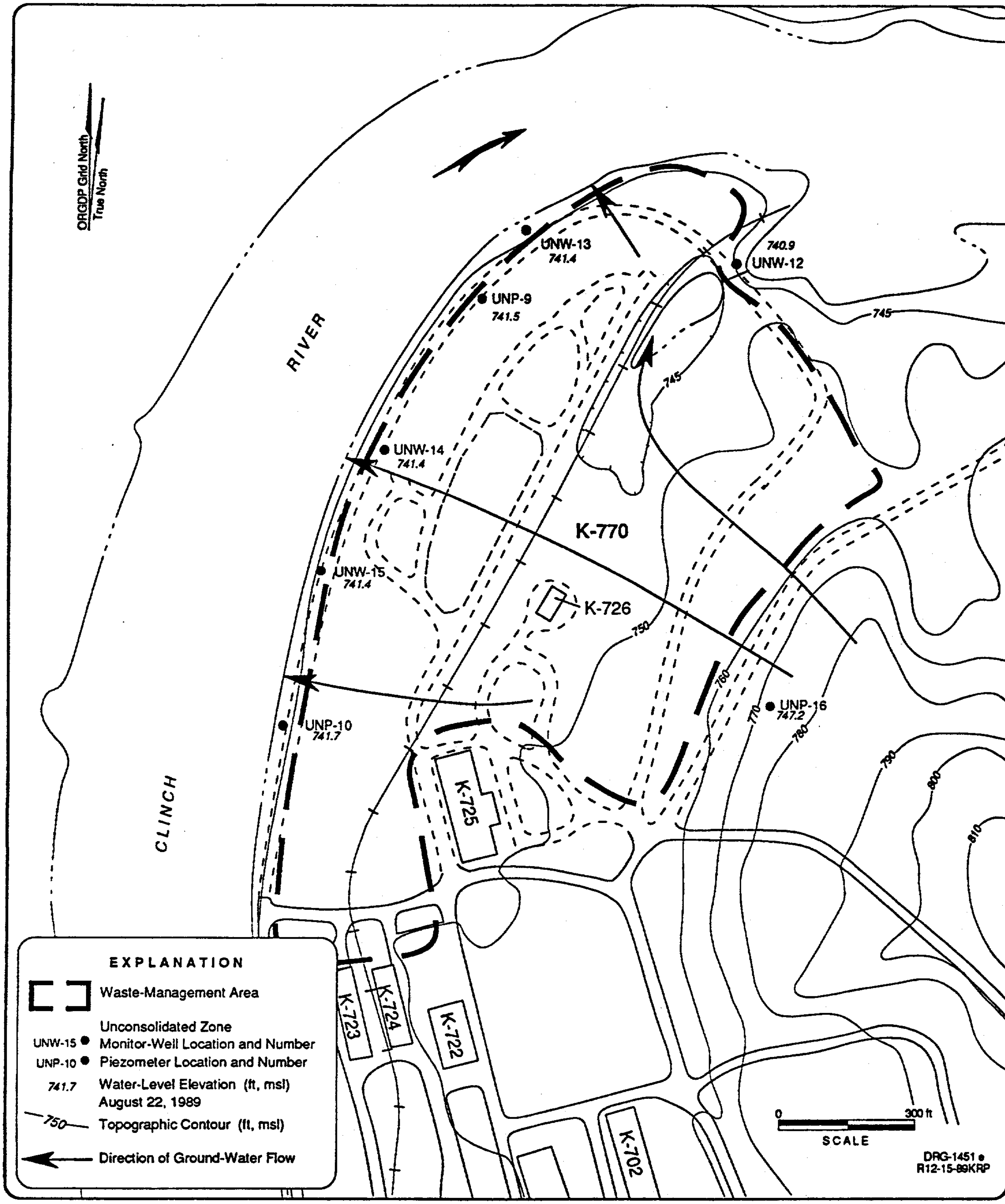


Figure A-9. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-770 Site

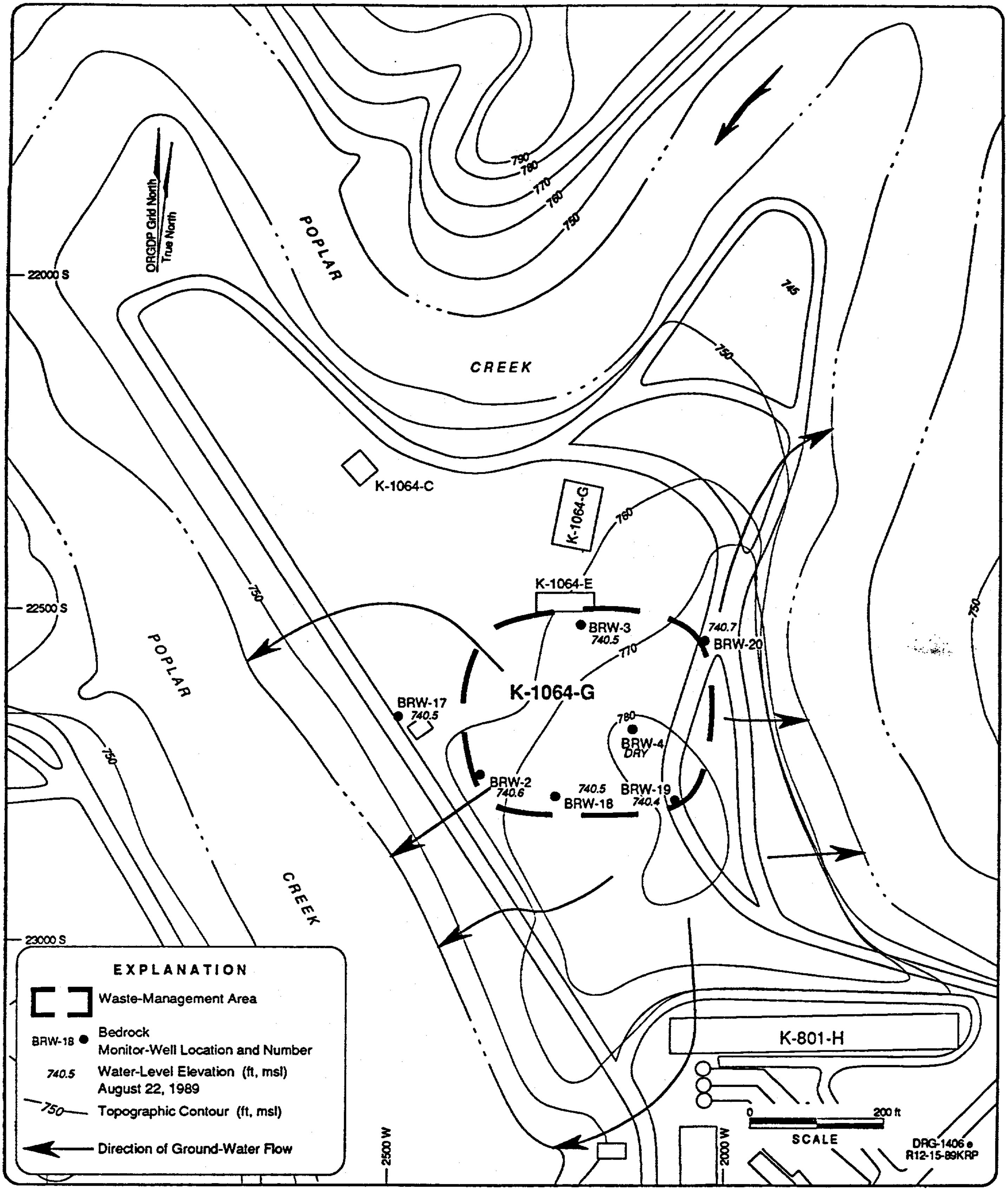


Figure A-10. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1064-G Peninsula Storage and Burn Area Site

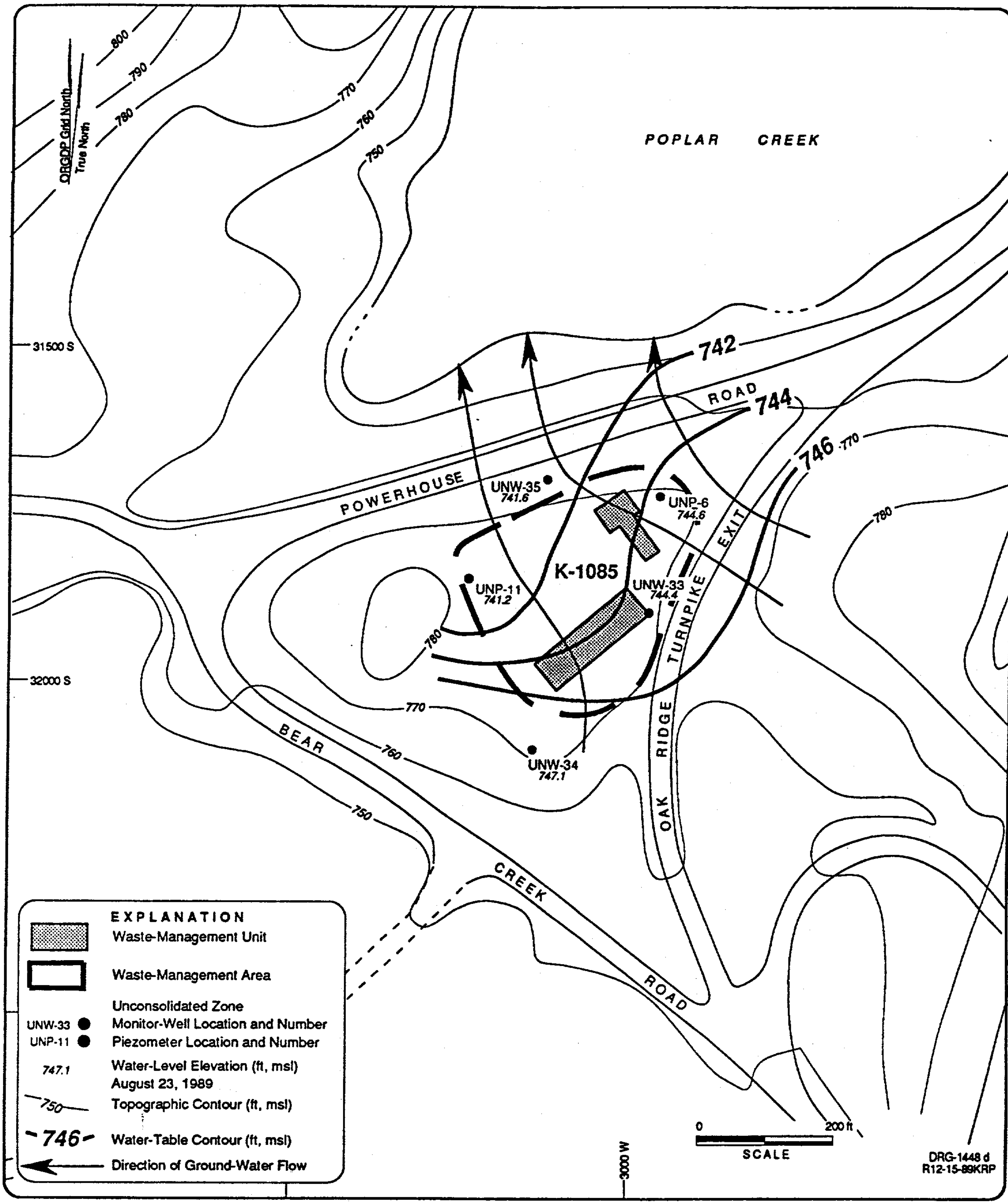


Figure A-11. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1085 Site

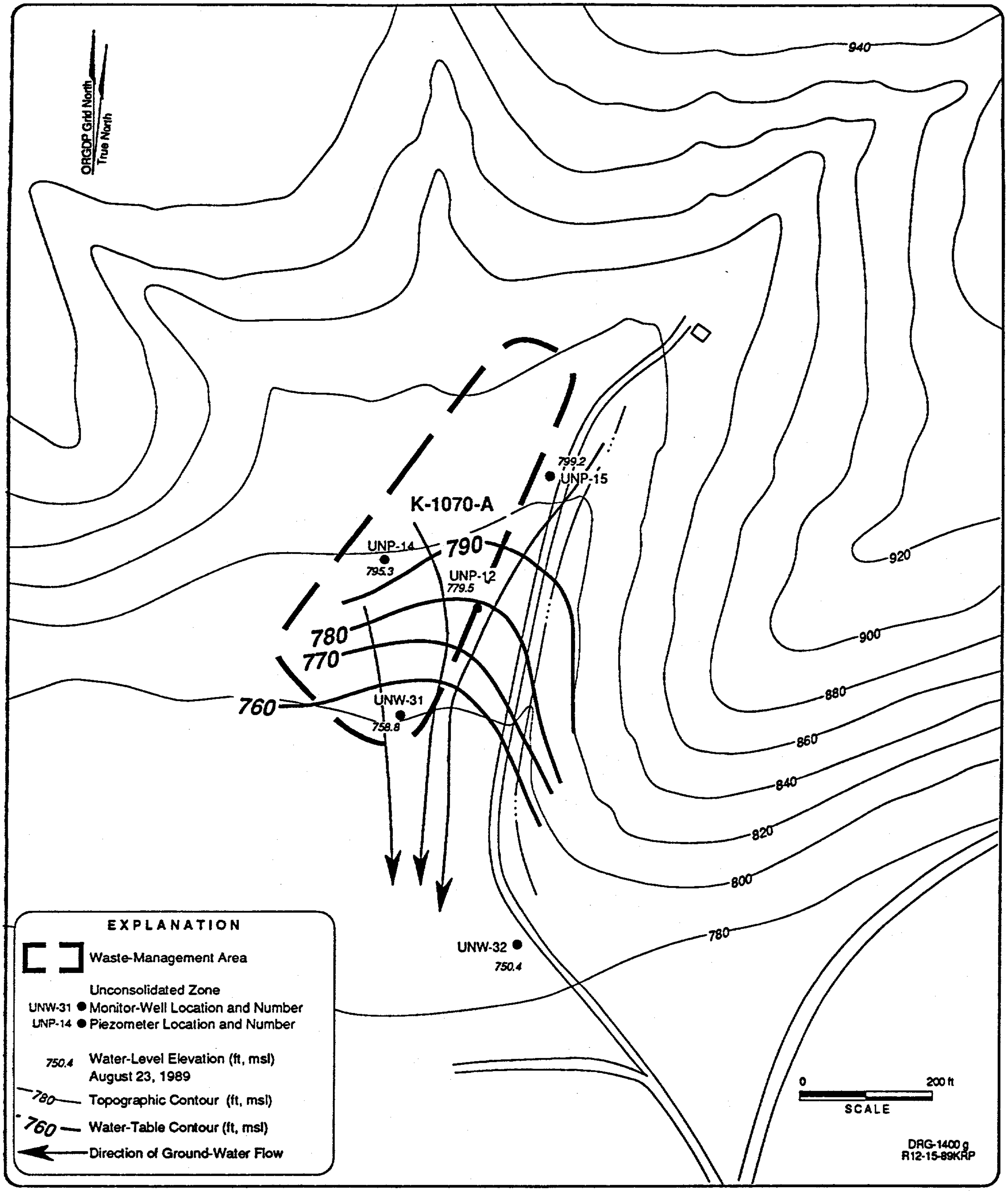


Figure A-12. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1070-A Site

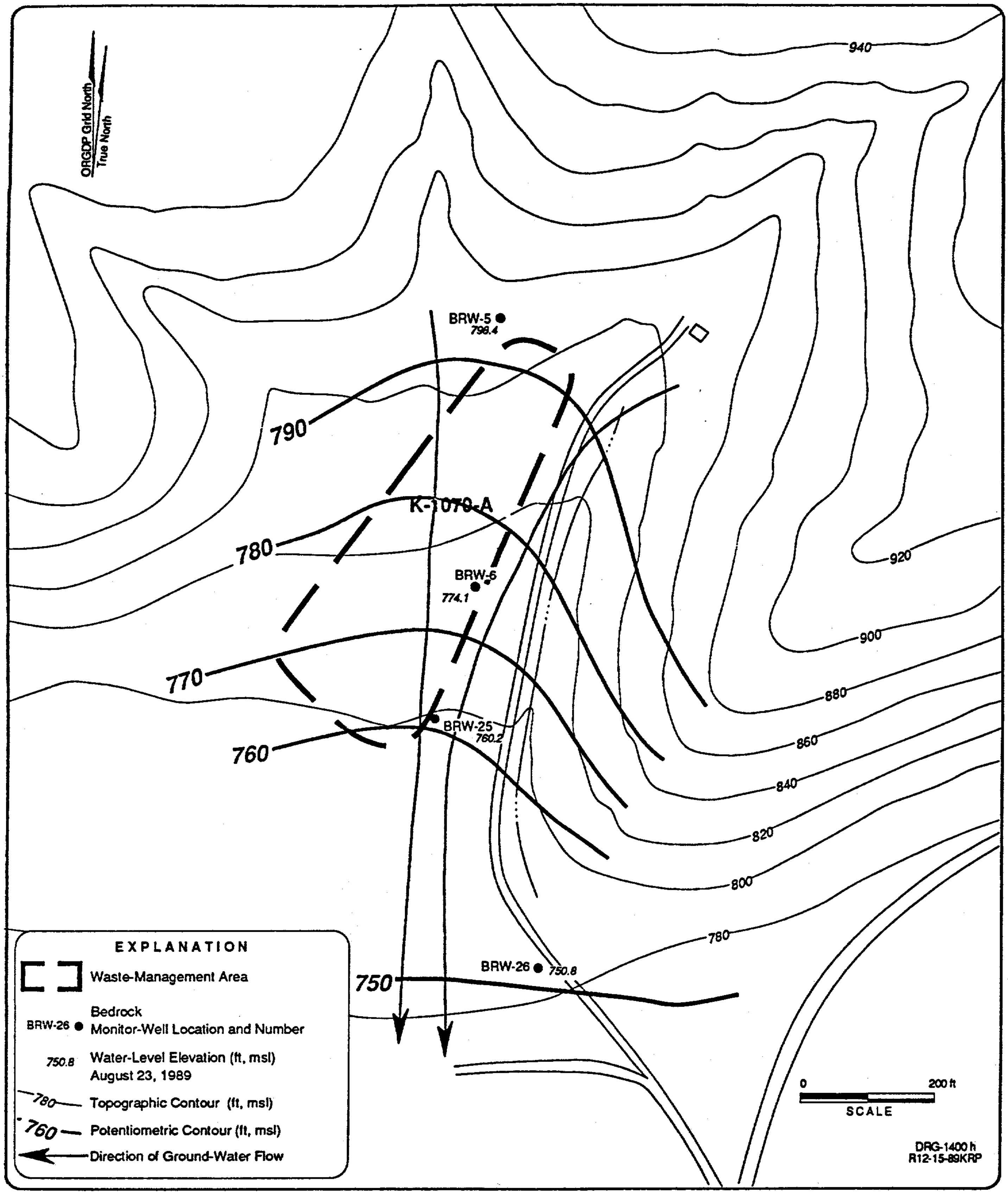


Figure A-13. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1070-A Site

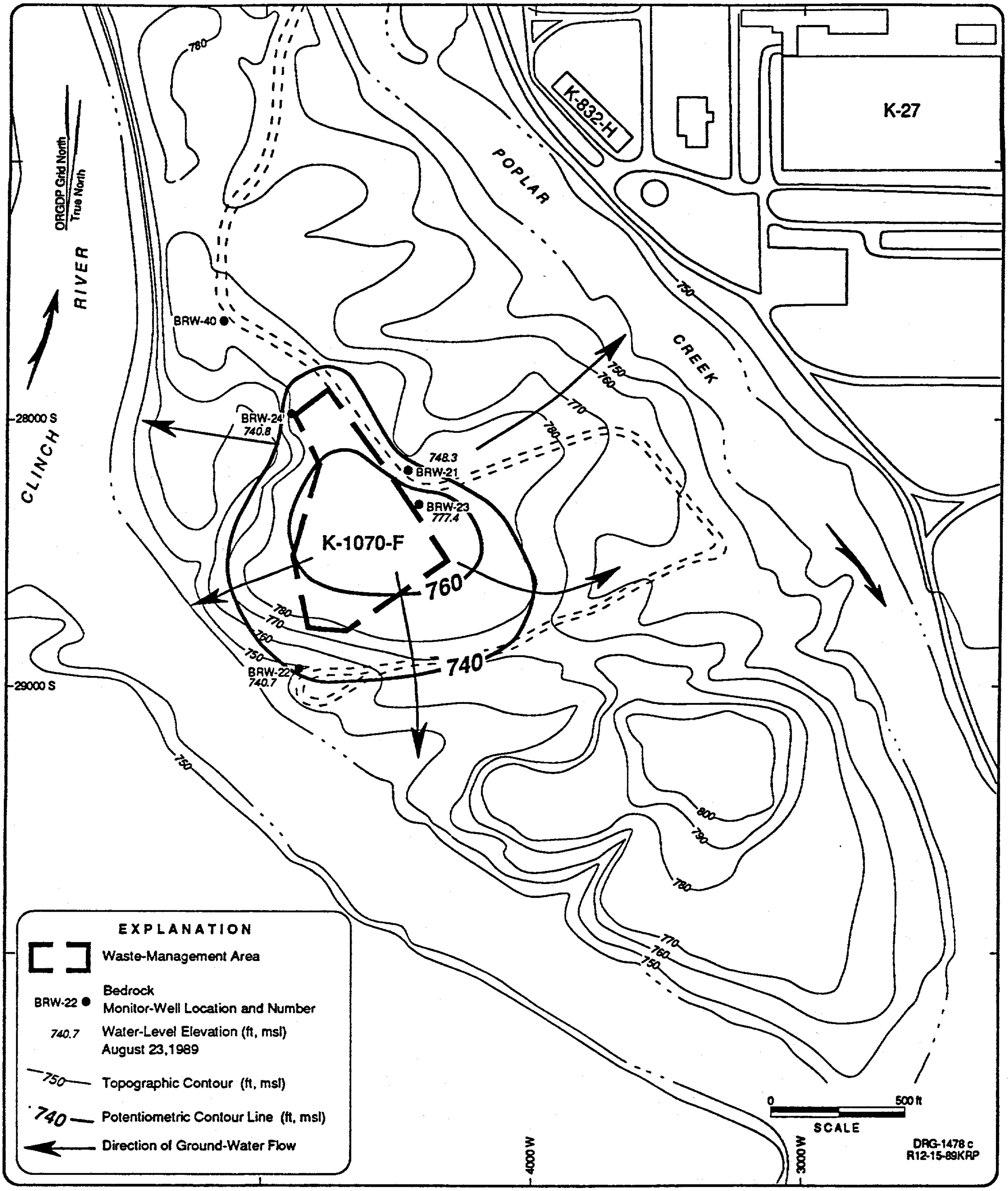


Figure A-14. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1070-F Site

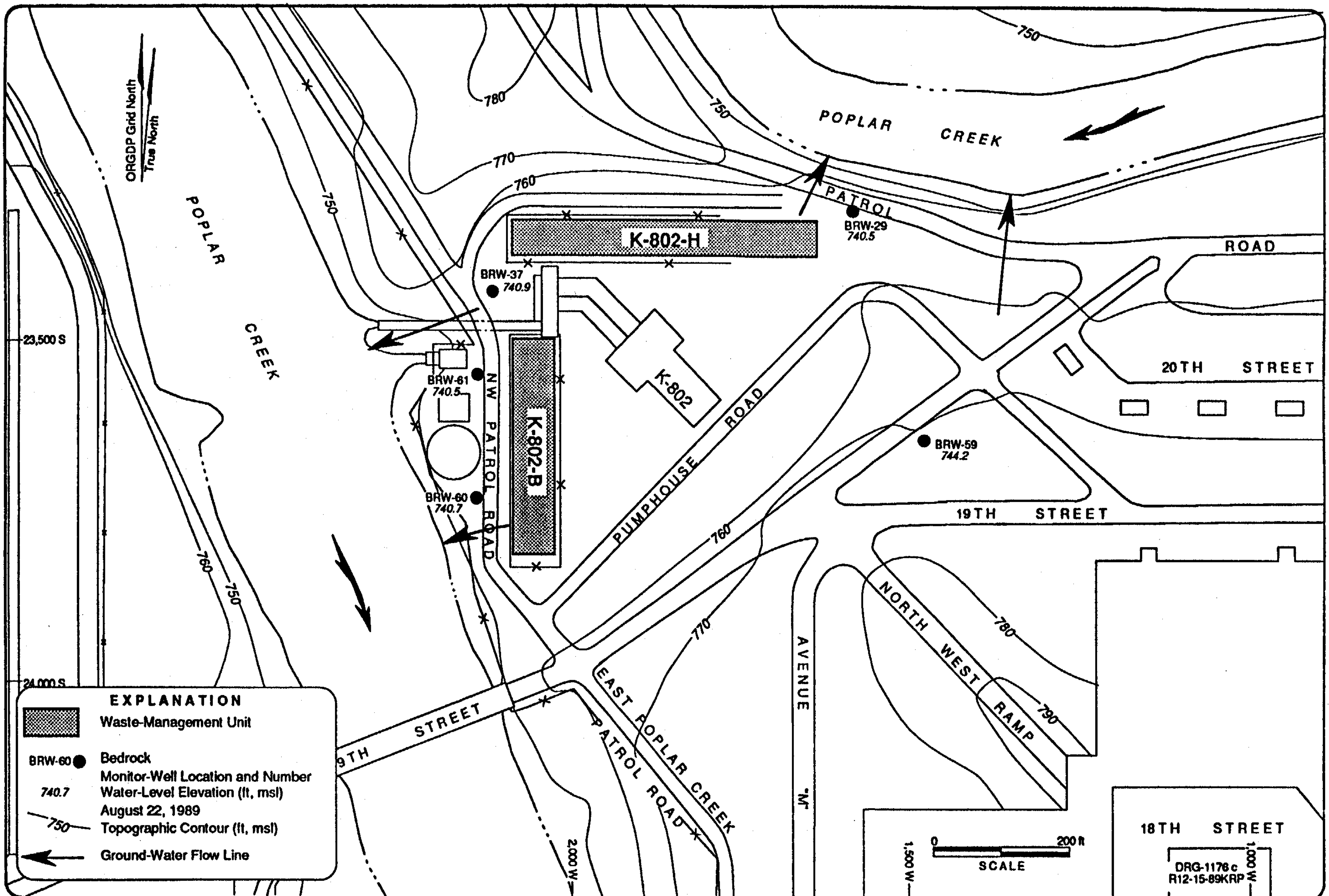


Figure A-15. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-802-B and K-802-H Sites

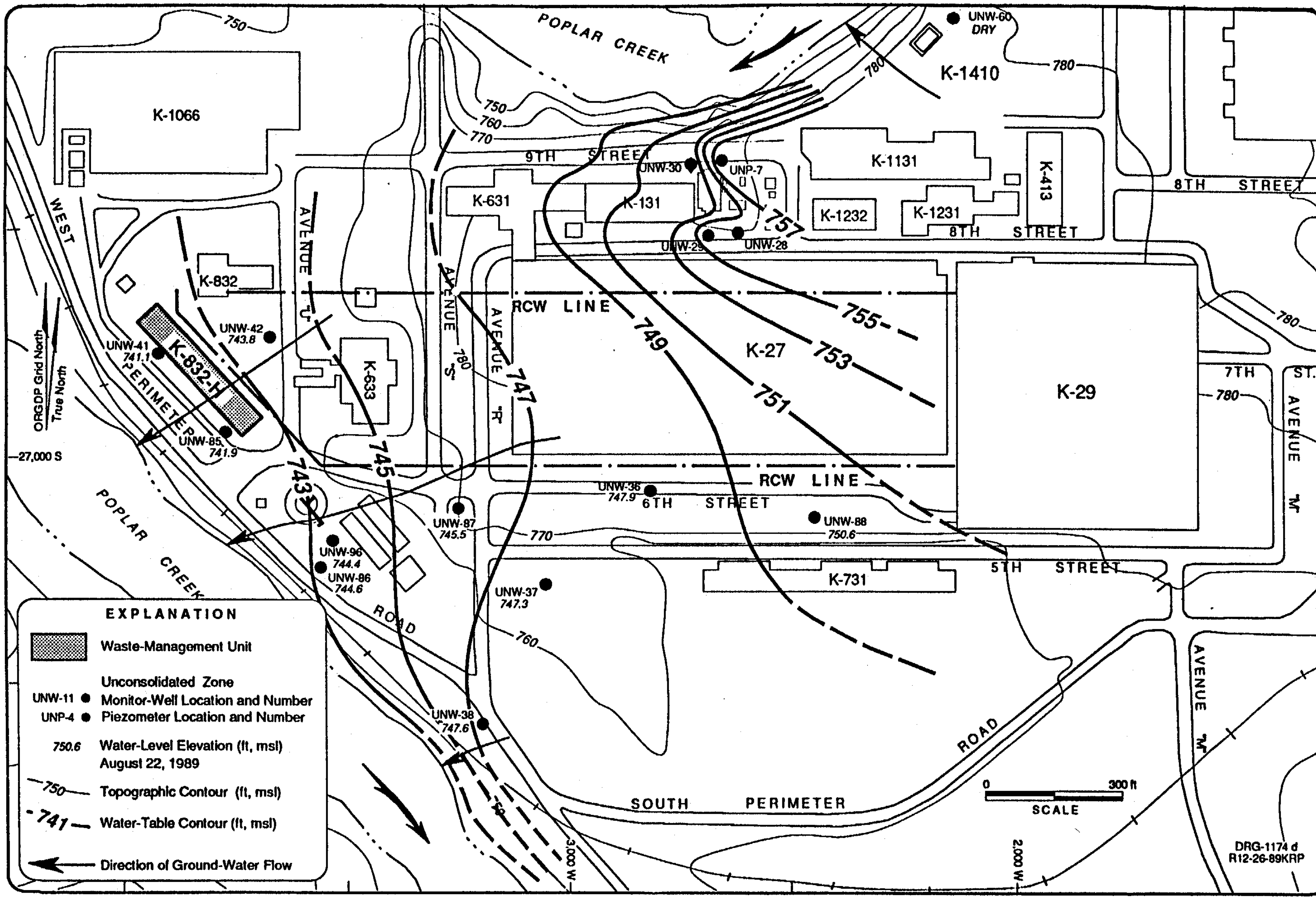


Figure A-16. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-27, K-29, K-832-H, and K-1410 Sites

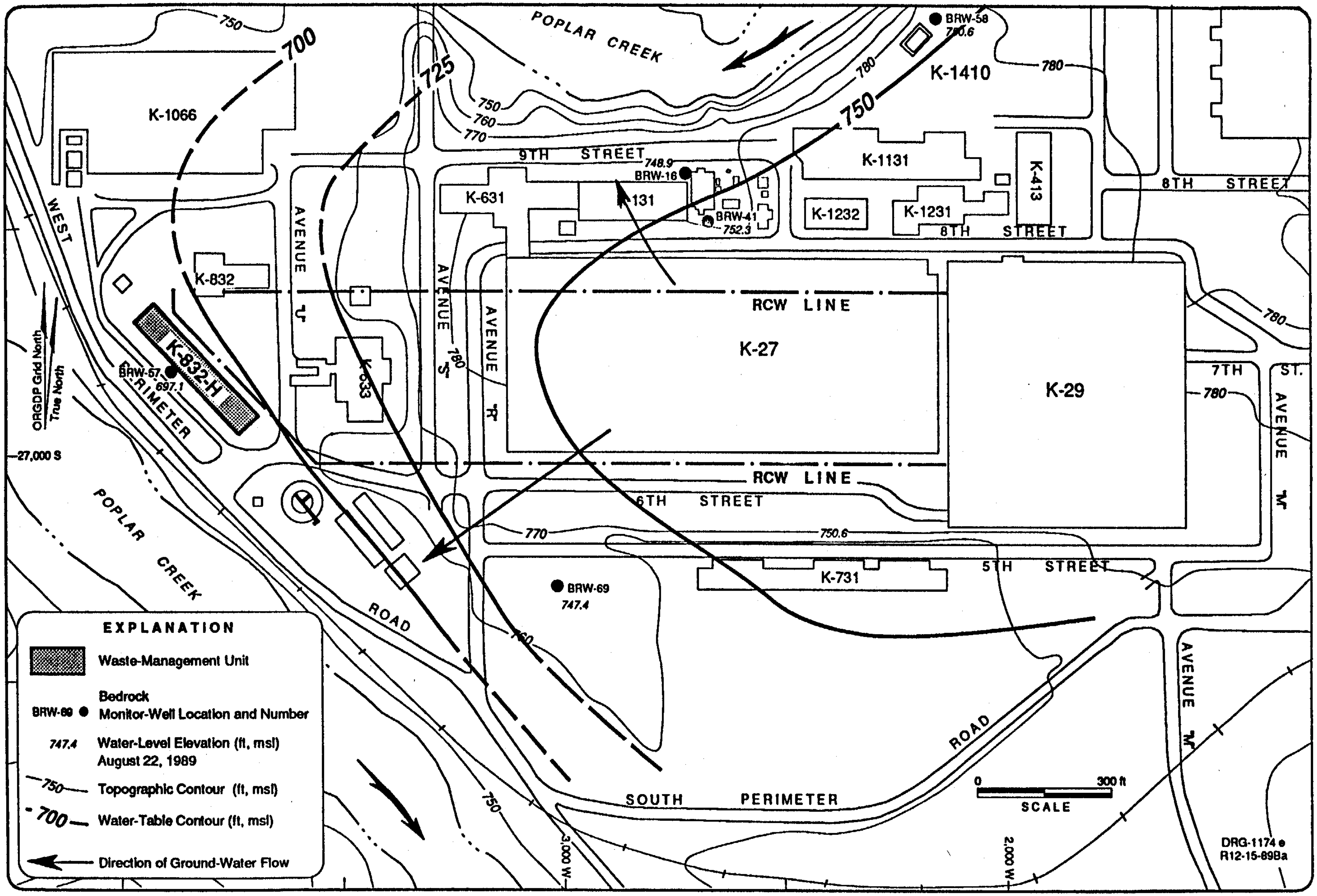


Figure A-17. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-27, K-29, K-832-H, and K-1410 Sites

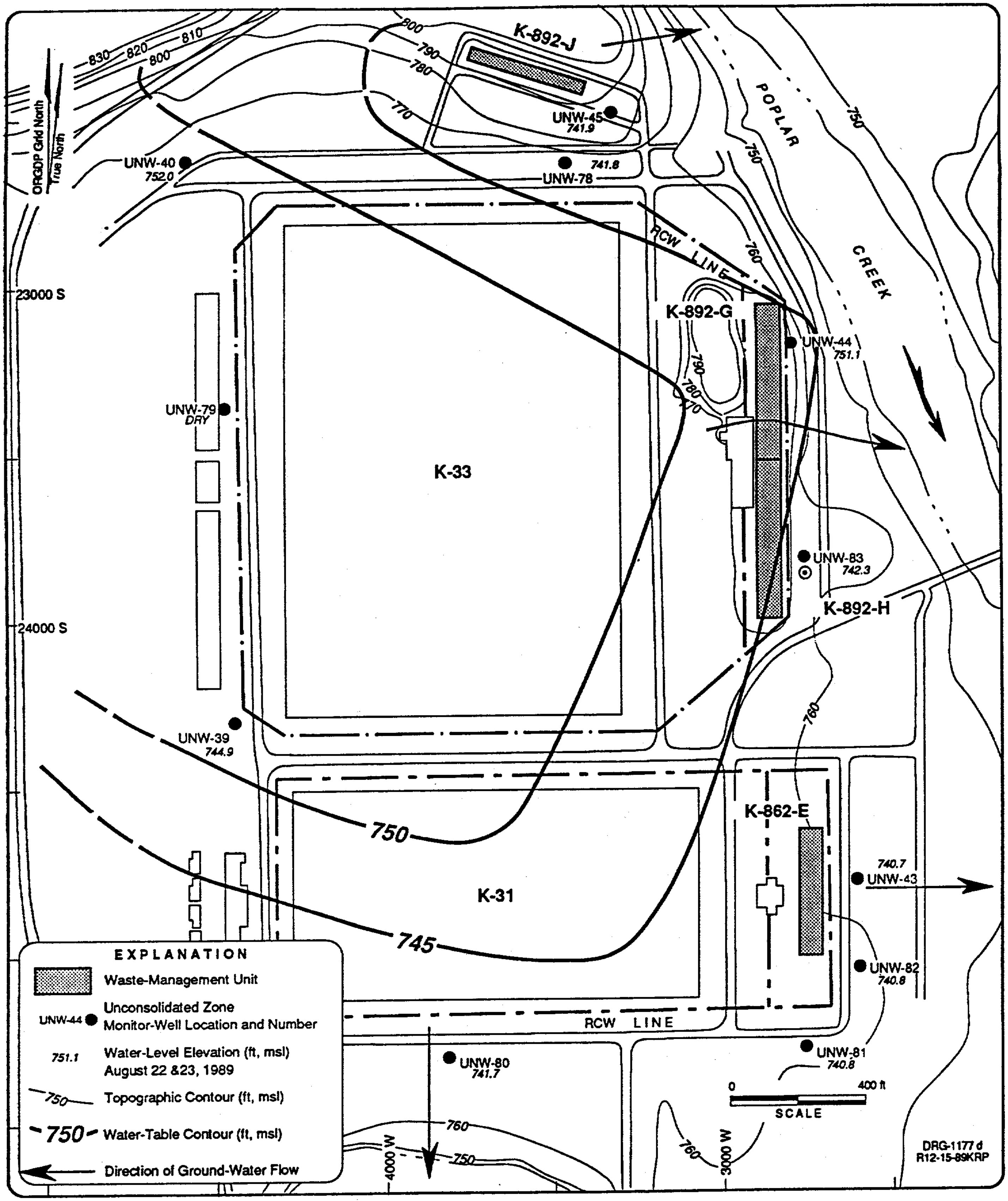


Figure A-18. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-31, K-33, K-862-E, K-892-G, K-892-H, and K-892-J Sites

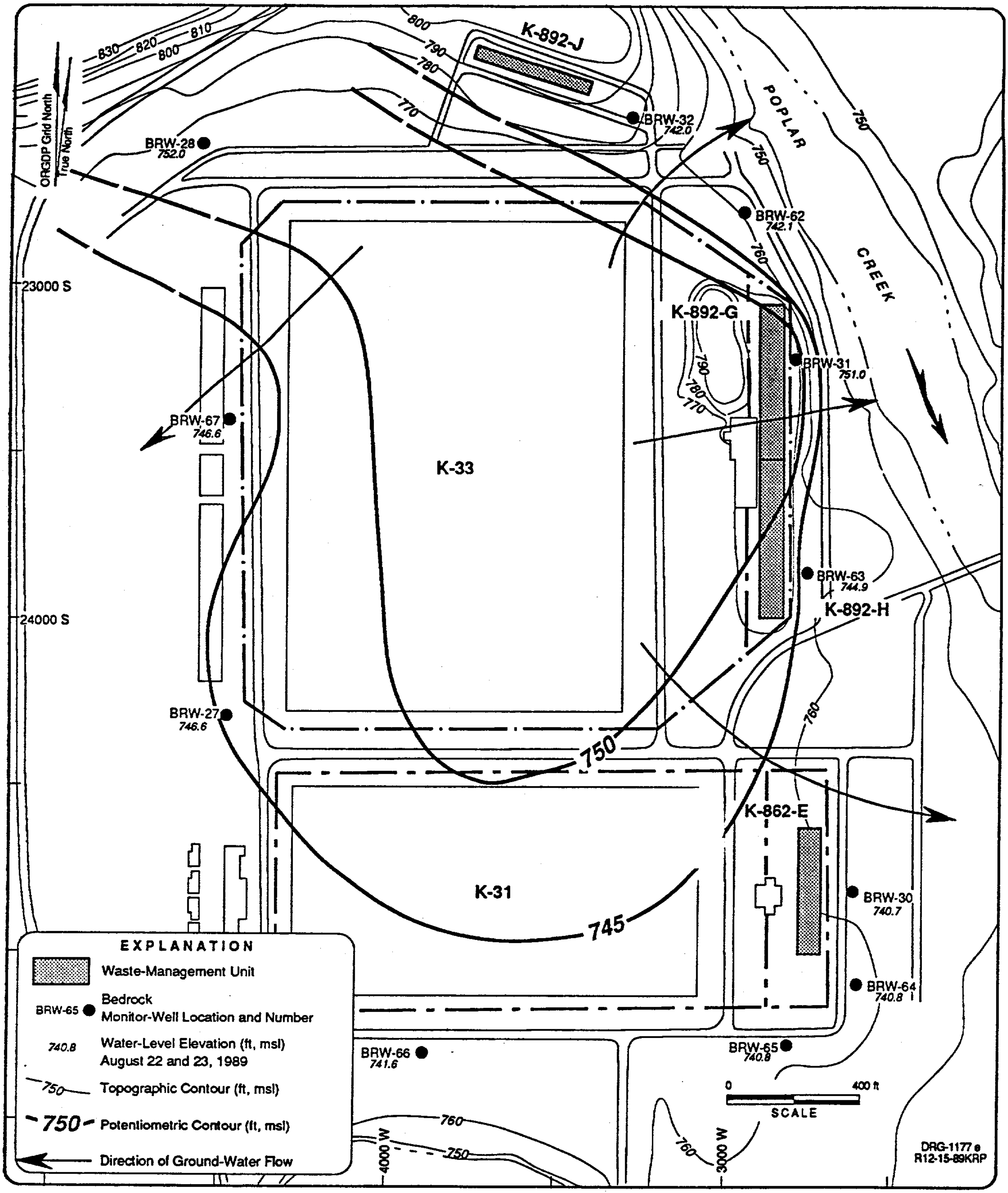


Figure A-19. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-31, K-33, K-862-E, K-892-G, K-892-H, and K-892-J Sites

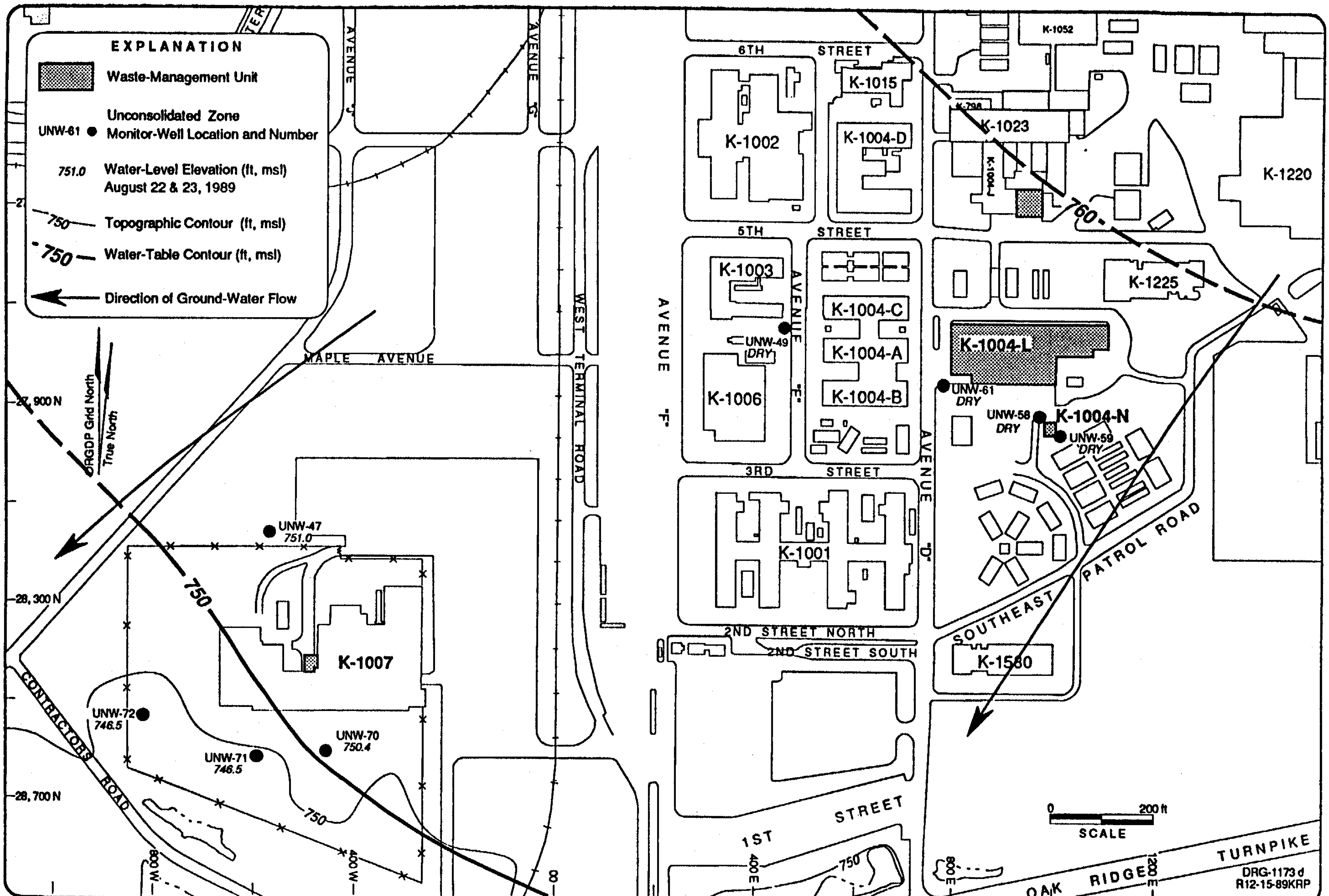


Figure A-20. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1004, K-1004-L, K-1004-N, and K-1007 Sites

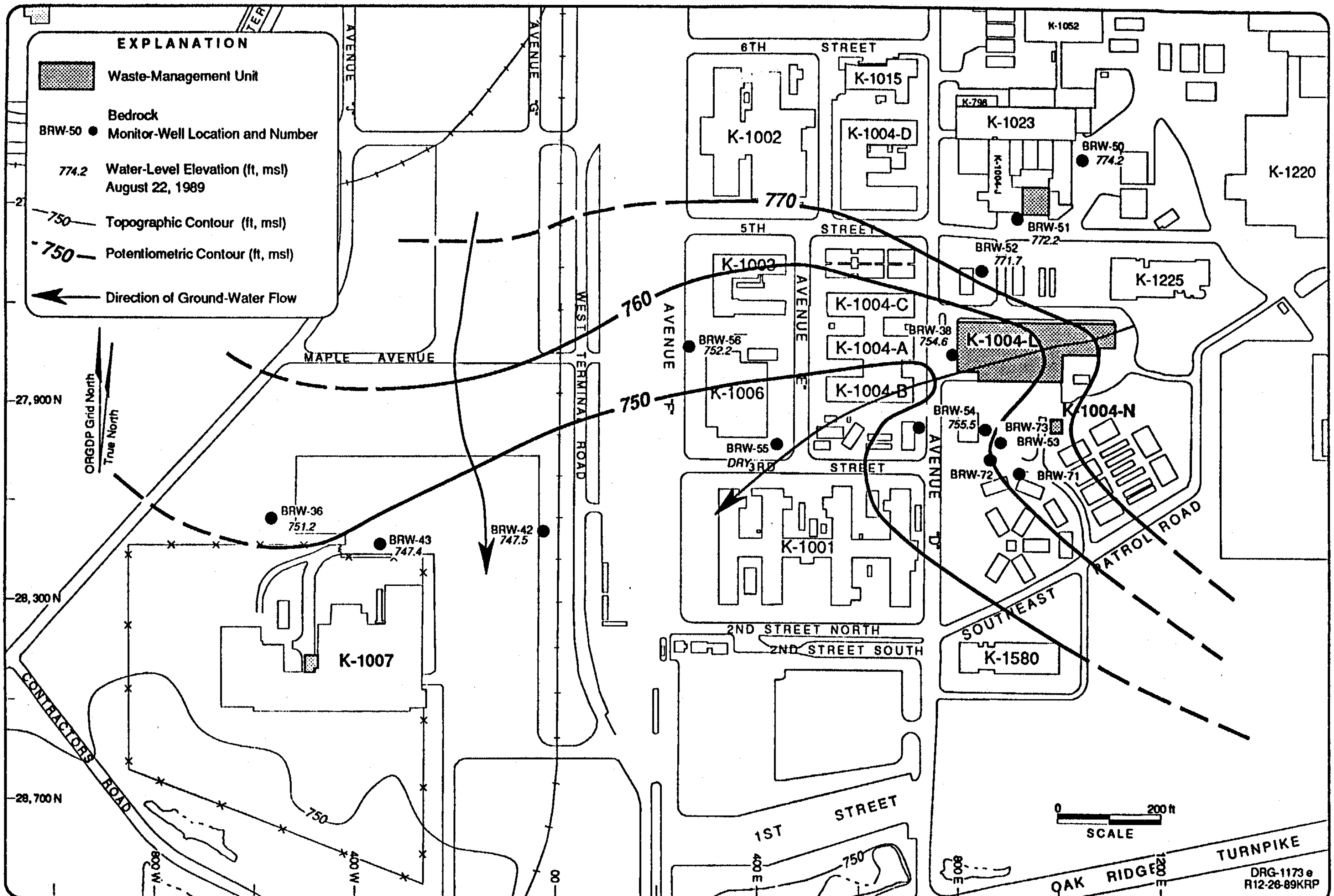


Figure A-21. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1004, K-1004-L, K-1004-N, and K-1007 Sites

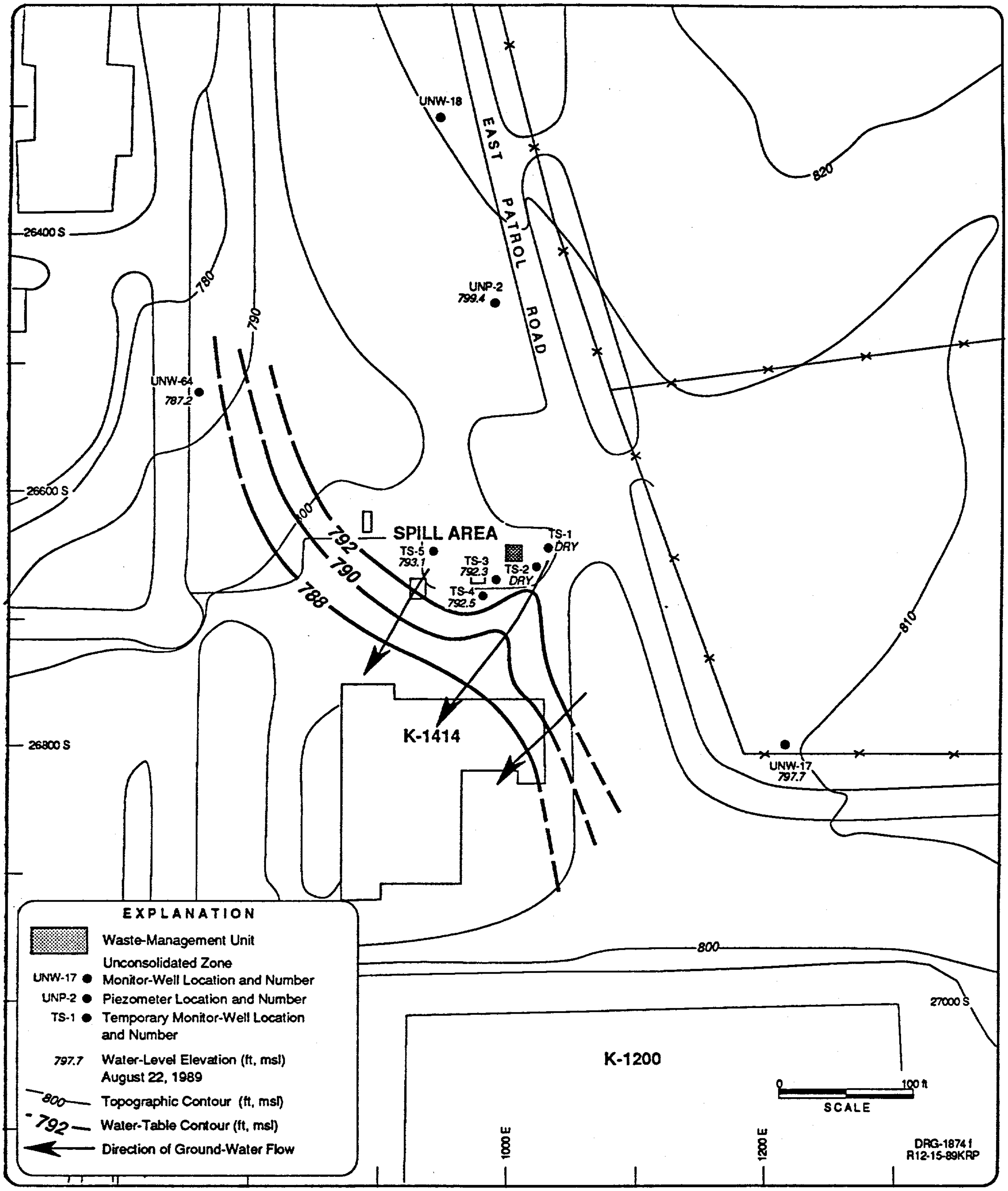


Figure 22. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1414 Site

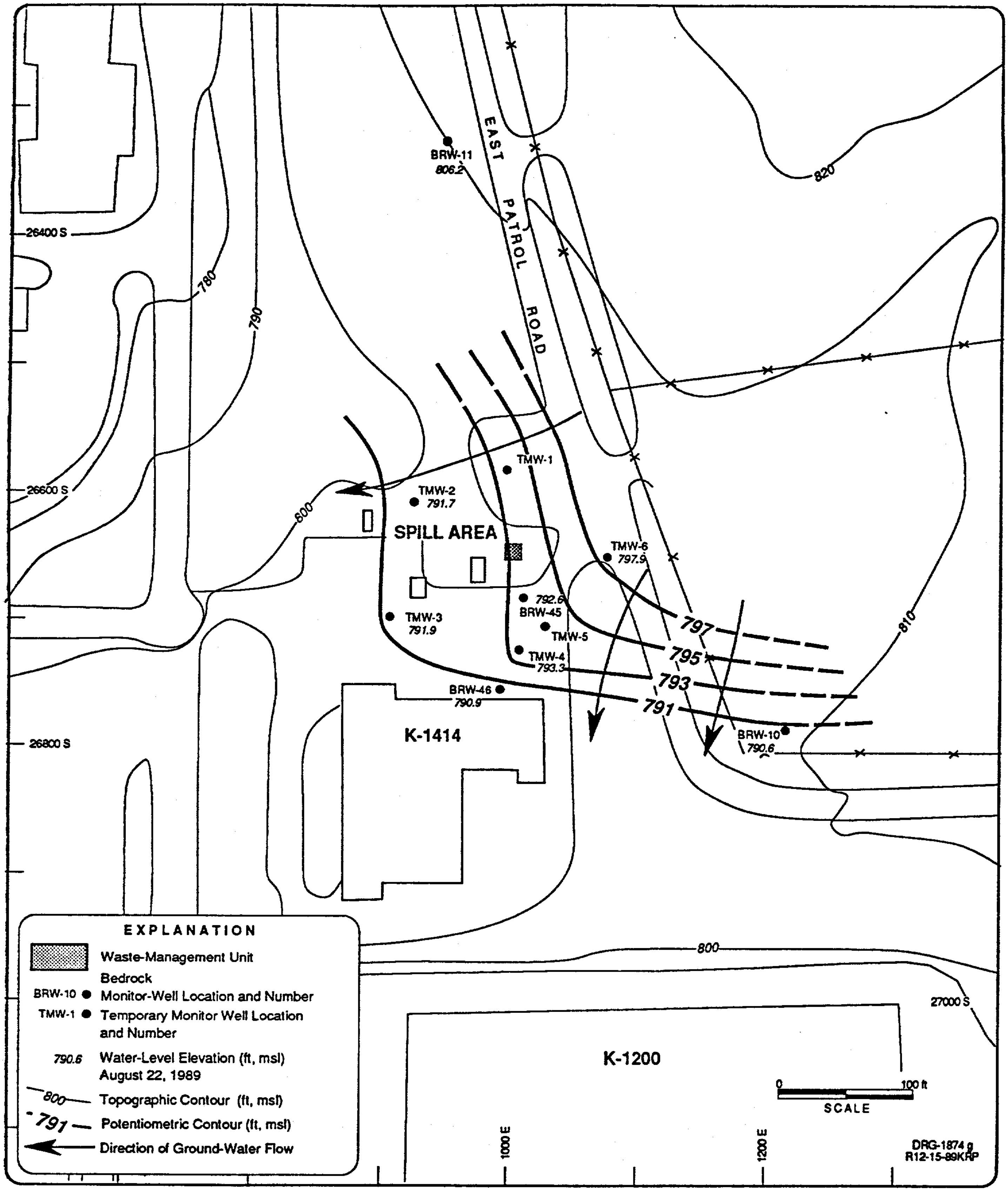


Figure A-23. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-1414 Site

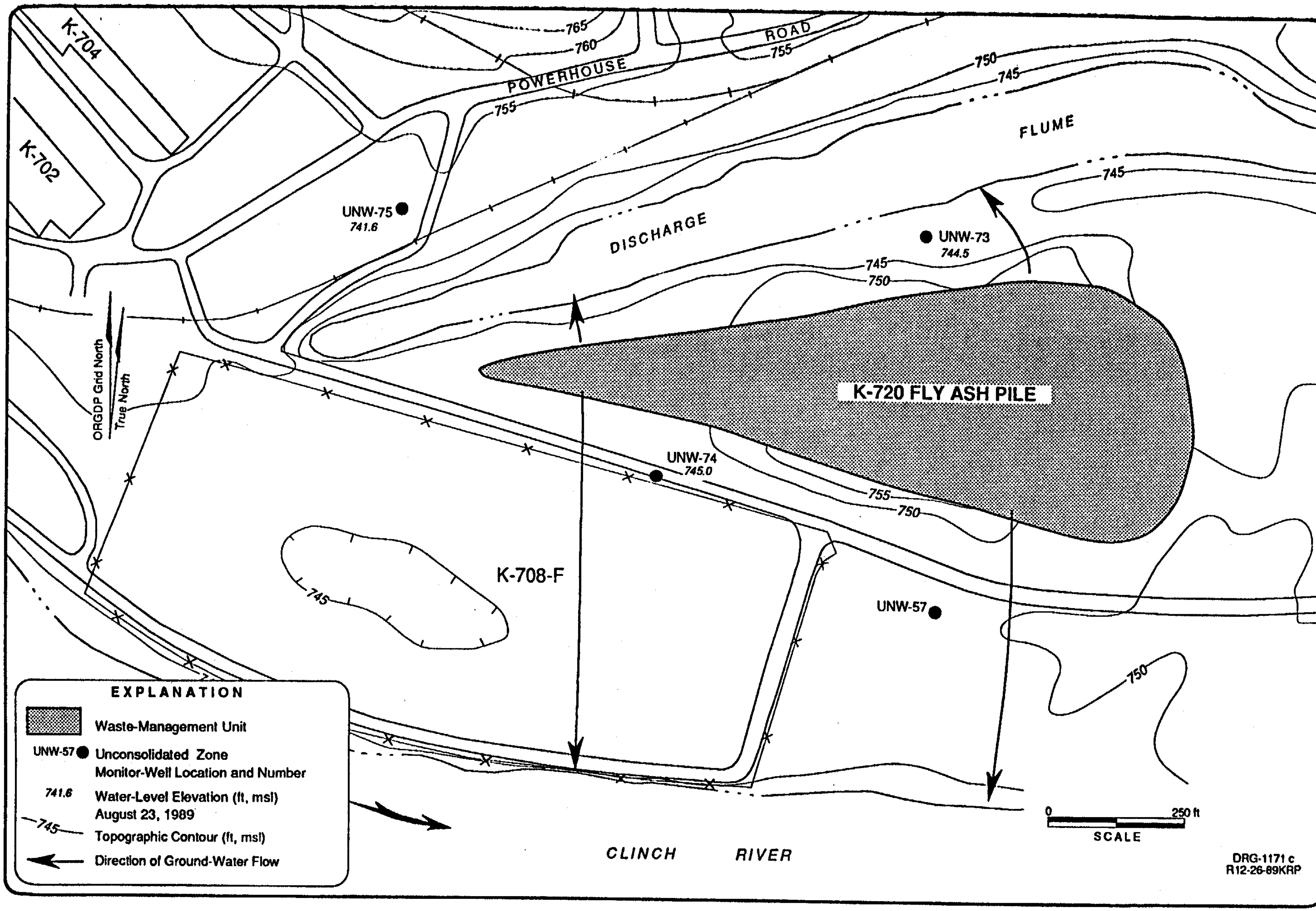


Figure A-24. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-1232 Site.

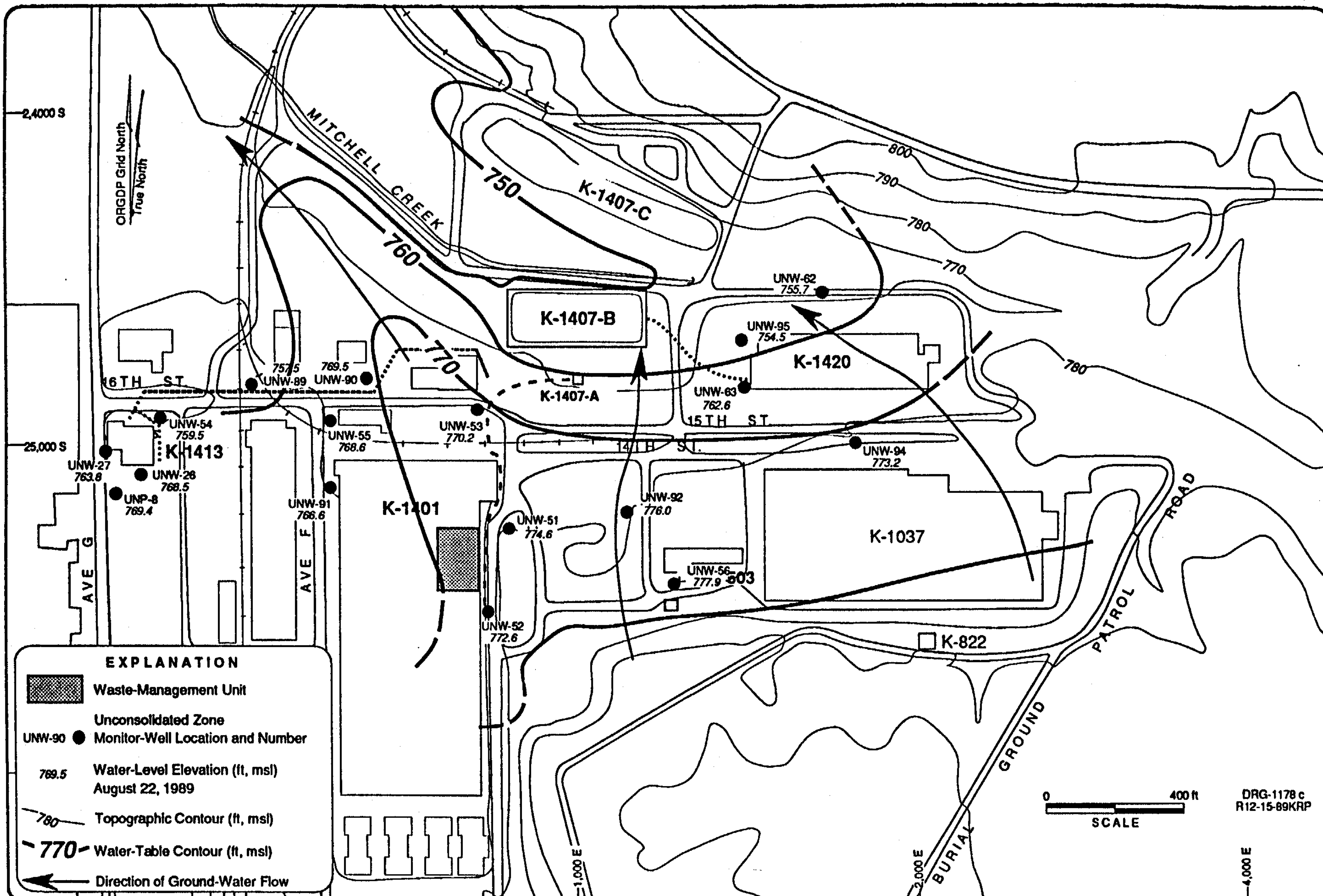


Figure A-25. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at K-1401, K-1413, K-1420, and K-1503 Sites

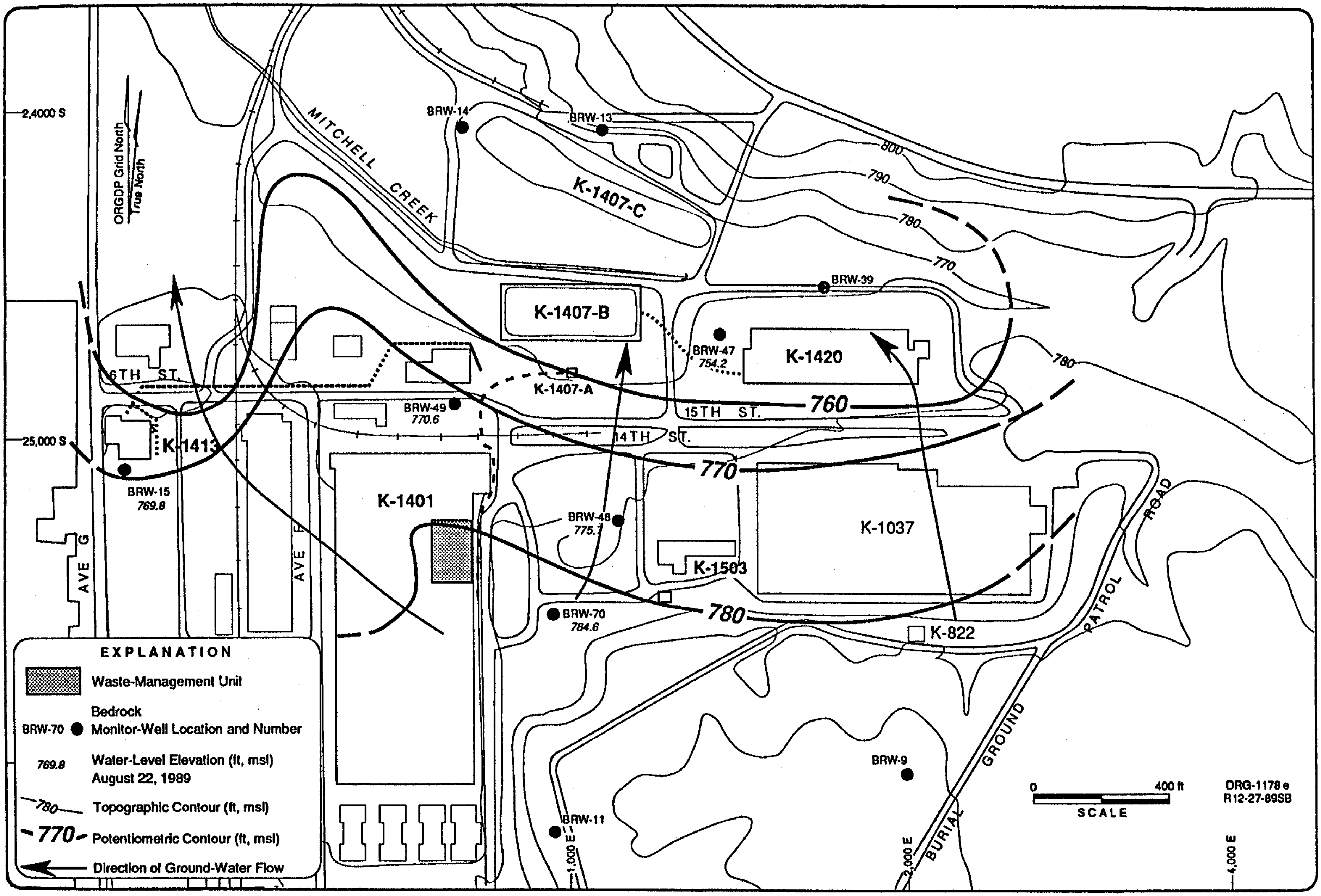


Figure A-26. Monitor Wells and Inferred Ground-Water Flow in Bedrock at K-1401, K-1413, K-1420, and K-1503 Sites

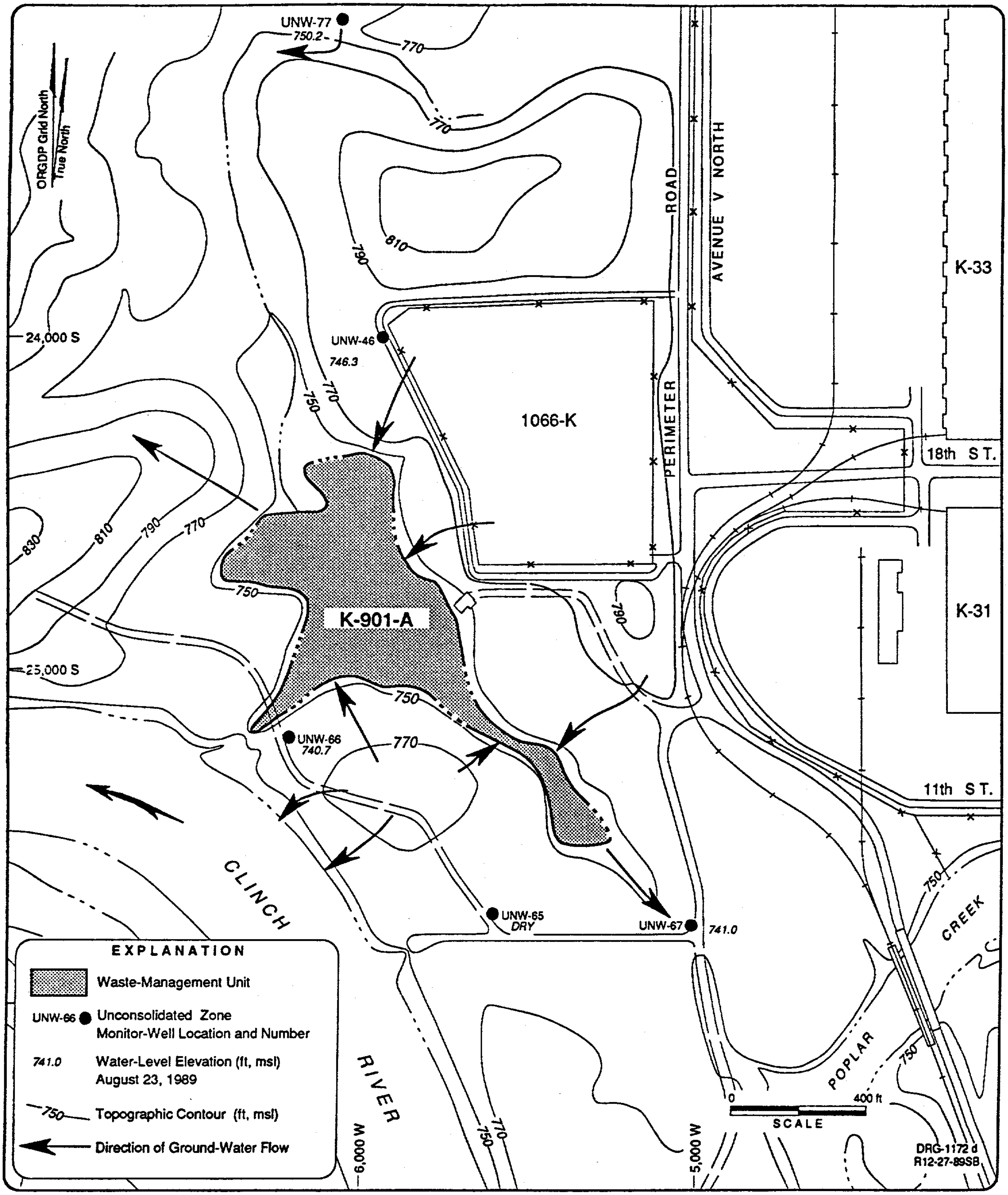


Figure A-27. Monitor Wells and Inferred Ground-Water Flow in the Unconsolidated Zone at the K-901-A Holding Pond Site

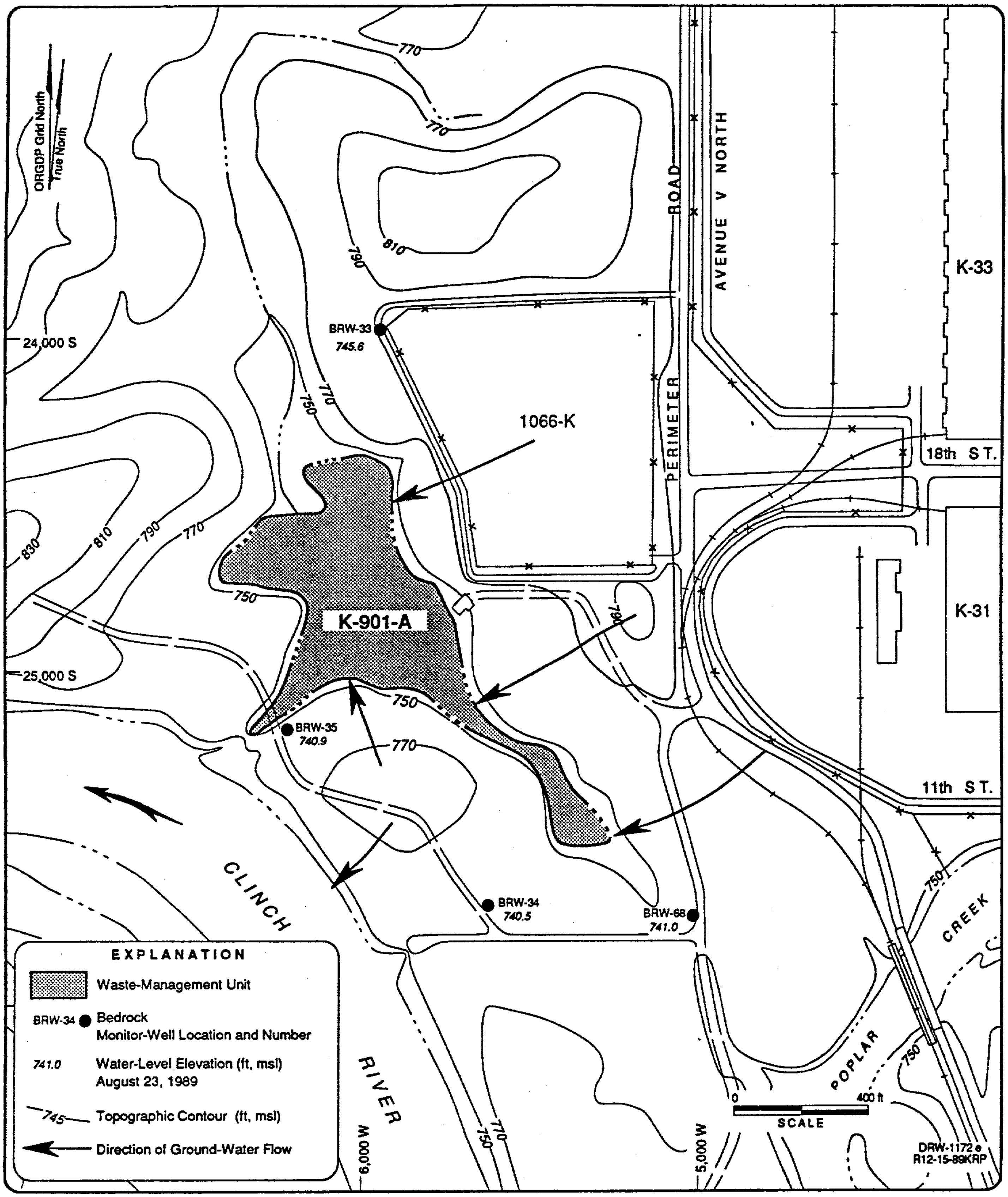
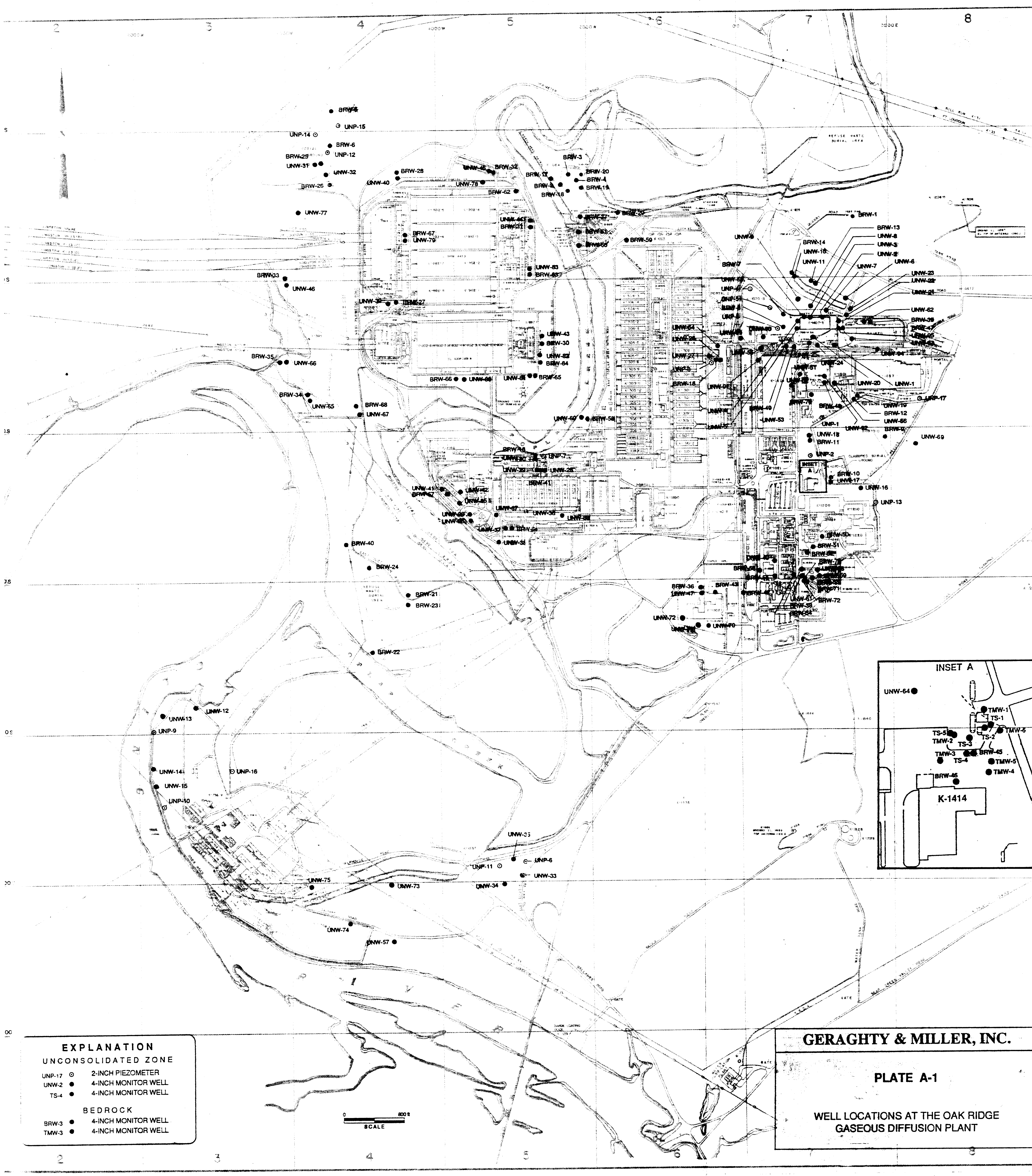


Figure A-28. Monitor Wells and Inferred Ground-Water Flow in Bedrock at the K-901-A Holding Pond Site


GERAGHTY & MILLER, INC.
PLATE A-1
WELL LOCATIONS AT THE OAK RIDGE GASEOUS DIFFUSION PLANT
EXPLANATION
UNCONSOLIDATED ZONE
UNP-17 2-INCH PIEZOMETER
UNW-2 4-INCH MONITOR WELL
TS-4 4-INCH MONITOR WELL
BEDROCK
BRW-3 4-INCH MONITOR WELL
TMW-3 4-INCH MONITOR WELL
0 800 ft
SCALE
INSET A
K-1414

#1158